COMPUTER PROGRAMS FOR TETHERED-BALLOON SYSTEM DESIGN AND PERFORMANCE EVALUATION

AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AIR FORCE BASE, MASSACHUSETTS

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Computer Programs for Tethered-Balloon System Design and Performance Evaluation

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Six computer programs were developed to provide both standardized methods for solution of typical tethered-balloon performance problems and improved techniques sufficient to study the very high altitude tethered-balloon system design problem. The programs are written for an HP-9810A desk computer but are fully documented for conversion to other types of equipment. Preliminary results are shown indicating the feasibility of a balloon tethered at an altitude of 20 km.

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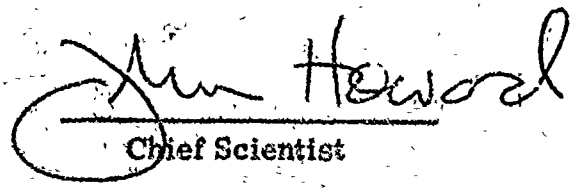
FOR THE COMMANDER:



Chief Scientist

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1. INTRODUCTION

In 1974 several agencies expressed interest in being able to loft several kinds of payloads on a balloon to very high altitudes and keep them overhead for periods of time ranging from several days to several weeks. The French government had partial success with a tethered balloon concept whereby the tether cable on its reel was carried up with a free balloon. It was programmed to drop its reel during ascent for ocean recovery and to continue its ascent to 18 km as a tethered system. This concept, demonstrated in equatorial latitudes, minimizes the drag loads since relative winds on ascending balloon and cable are very small.

The Aerospace Instrumentation Division of AFGL decided that a method involving a fixed ground station such as would be required at a missile test site must be evaluated. An altitude of 20 km was selected because of its desirability for several kinds of projects. A series of tests to select an optimum Kevlar cable was begun and will be reported in a separate document. A balloon design has been selected and will undergo a preliminary test as a free-balloon early in 1977. The results of this test as well as the actual tether feasibility test to be made in August 1977 will also be separately reported.

(Received for publication 25 August 1976)

This report covers an outgrowth of the study of the high-altitude system design. One of the needed parameters is the tether-cable length in order to have a proper amount available and a balloon sized to lift both the payload and the cable under many different atmospheric conditions. Many other quantities are also needed for a realistic and scientific approach in the design of a high altitude tethered balloon system. It was found that several existing computer programs were based on limited assumptions of, for example, constant cable drag coefficients or winds.

In deriving a more realistic cable program, it became apparent that two of the principal inputs defining the upper-end condition of the cable were the total balloon upward force, and its angle to the horizon. The balloon provides buoyant and aerodynamic lift in the vertical direction and drag in the horizontal direction. The two aerodynamic forces change with a balloon's angle of attack and this angle in turn is governed by not only aerodynamic characteristics but other design parameters as well.

Hence other programs were developed to provide the balloon characteristics for any range of altitudes or balloon types. This report describes those programs developed to date in sufficient detail to allow their use directly or, by adaptation, with any computer system. In Section 5, some results of the study of the high-altitude, tethered-balloon using one of the computer programs are examined.

2. TETHERED-BALLOON COMPUTER PROGRAMS

As is found in many special technological fields, there are many day-to-day tethered-balloon problems requiring repetitive calculations. Some of these are quite simple in nature, some are practically solvable only by means of a computer, and many lie somewhere between the above extremes. Each problem may be set up differently each time it is encountered depending on the time allowed to answer some question, the particular predilections of the person undertaking the task, and the mathematical aids used.

This report attempts to provide some uniformity in techniques, assumptions, and precision by offering a series of tethered-balloon programs designed for an office type of computer. Most organizations engaged in such work have a large digital computer department. However, certain formalities in procedures, lack of personal control by the user, and some degree of awe by many engineers do not yet allow the master computer to be a universally acceptable tool capable of fast response.

A desk computer of the capacity considered herein is a remarkably capable machine for solution of the most lengthy and reiterative problems encountered in designing or analyzing existing tethered-balloon systems. Its closeness to the

engineer allows its use for an immediate answer. Due to familiarity generated by complete user control, it becomes amenable to experimentation with many variations in program input or even content when properly documented. In addition, the nature of balloons requires that some field operations be conducted in remote areas of the world where only a desk computer can be made available as a part of the ground base equipment.

The programs presented herein were developed for use in a Hewlett-Packard Model 9810A desk calculator/computer. The particular instrument used has 2036 program steps (Option 003), 111 storage registers (Option 001) and a tape printer (Option 004). All programs require the MATH-ROM (No. 11210A). Some programs require less than the full number of program steps and storage registers as can be noted in their respective descriptions.

The programs can be converted to other models or brands of desk computers using Reverse Polish or none RP logic or units having fewer program steps. With the latter in mind, the programs were written with minimum use of subroutines so that they may be divided more easily into several shorter complete programs. They are not meant to be models of programming efficiency and do not utilize every nuance of logic or operation which the HP 9810A offers. They are meant to be utilized by engineers who may wish to change some internal elements or constants but without having to develop a new program.

Each program is documented in subsections as follows:

(1) Description of physical problems,

(2) Description of the program development including the detailed mathematics, physics, aerodynamics, etc., involved in the problem solution.

(3) Flow chart,

(4) Operating instructions,

(5) Input data form,

(6) Program listing,

(7) Sample of printed output,

(8) Notes for user, including possible changes in program.

Table 1 provides an overview of the six programs presented with a brief description of their usage and capability. Program No. 76.001 can be used typically for a rapid determination of what balloon in an inventory is capable of performing a special task. It treats the no-wind condition which is indicative of the smallest balloon capable of the particular task. It also provides for multi-cable geometry and checks the ballonet for adequacy to cover the specified altitude range.

Program No. 76.002 is also a no-wind program for examination of the effects of center-of-gravity and center-of-buoyancy position relationships. Programs 76.003, 004, and 005 may also be used for similar studies although they were primarily designed with wind to calculate all balloon forces and to obtain the net total

force and its angle when the balloon is at the trim condition for input into 76.006, the tether-cable program. No. 76.003 is intended for any balloon type or shape whereas 76.004 and 76.005 are specialized for the Family-2 balloon design. These latter two are shown as written for a 45,000 CF balloon but directions are provided for simple changes to cover universal applications.

A typical balloon problem was established and used in Program Nos. 76.001, 004, 005 and 006 to illustrate their printed input and output information.

Table 1. Tethered-Balloon Computer Programs

<table>
<tr><th colspan="2">USAGE</th><th colspan="2">PROGRAM</th></tr>
<tr><td colspan="2">Selecting Min. Stock Balloon For Given Payload and Test Config.</td><td colspan="2">76.001 BASIC BUOYANCY
Wind = 0, Any single altitude and surface altitude, 1 to 5 cable configuration
Checks: Ballonet/Altitude Acceptability
Provides: Gross and Net Lift at Surface
Multi-Cable Geometric Parameters</td></tr>
<tr><td colspan="2">Analysis of Balloon Geometry</td><td colspan="2">76.002 GENERAL T-BALLOON
Trim, Wind = 0, any single altitude, optional matrix variation of CG and CB locations
Provides α trim at input or matrix values of CG and CB locations.</td></tr>
<tr><td rowspan="3">Analysis of System Flight Conditions</td><td rowspan="2">Balloon Trim and Total Force Req'd for</td><td></td><td>76.004 FAMILY-2 T-BALLOON
Trim, any wind value, design altitude condition where ballonet empty
Provides: α trim, F_T, θ</td></tr>
<tr><td>76.003 GENERAL T-BALLOON
Trim, any set of wind profiles, any altitude range from ballonet empty to full
Provides: α trim, F_T, θ, etc, over range of altitudes.</td><td>76.005 FAMILY-2 T-BALLOON
Trim, any set of wind profiles, any altitude range from ballonet empty to full
Provides: α trim, F_T, θ, etc, over range of altitudes.</td></tr>
<tr><td>Tether Cable Parameters</td><td colspan="2">76.006 TETHER CABLE, TWO DIMENSIONAL
Single cable, any set of wind profiles, (F_T and θ input required)
Provides: Tension, angle, and space position of all points of cable from balloon to surface.</td></tr>
</table>

Table 2 is provided in order to fully define the program listings which are direct copies of the output tape (less number code). As can be noted, certain codes in the listing have double meaning depending on whether the system is in or not in an alpha-numeric print mode.

Table 2. Definitions of Program Codes

A. Standard Mode

In the explanation below, x, y, and z represent the contents of display registers x, y, and z, respectively; a and b represent the contents of memory registers a and b, respectively. The mnemonics and their respective functions are shown below:

Mnemonic	Function
π	$\pi \rightarrow x$
b	$b \rightarrow x$
a	$a \rightarrow x$
YTO	$y \rightarrow$ memory address which follows
XTO	$x \rightarrow$ memory address which follows
1/X	$1/x \rightarrow x$
IND	Used for indirect addressing
XFR	Puts the value in the following memory address into x
XSQ	$x^2 \rightarrow x$
RUP	$x \rightarrow y,\ y \rightarrow z,\ z \rightarrow x$
DN	$z \rightarrow y,\ y \rightarrow x,\ z \rightarrow z$
XEY	$y \rightarrow x,\ x \rightarrow y,\ z \rightarrow z$
UP	$x \rightarrow y,\ y \rightarrow z,\ x \rightarrow x$
$\sqrt{}$	$\sqrt{x} \rightarrow x$
DIV	$y/x \rightarrow y$
X	$xy \rightarrow y$
-	$y - x \rightarrow y$
+	$y + x \rightarrow y$
CHS	$-x \rightarrow x$
EEX	Used when assigning an exponent to a number being entered into x.
CLX	Set x to 0.
0 through 9	0 through 9, respectively, into x.
	Used to put a decimal point in a number being entered into x.

CLR	Set to 0, x, y, z, a and b.
CNT	Used as a null operation within a program. Used to run a program.
LBL	Used in conjunction with a following symbol to indicate a position in the program memory.
FMT	Used to enter (FMT, FMT) and leave (FMT) the print mode.
PNT	Prints the value of x; when multiple PNT's are used, lines are skipped after x is printed.
X<Y	If x<y, jump to the address indicated by the number given in the next 4 steps; if not, skip the next 4 steps.
X=Y	If x=y, jump to the address indicated by the number given in the next 4 steps; if not, skip the next 4 steps.
X>Y	If x>y, jump to the address indicated by the number given in the next 4 steps; if not, skip the next 4 steps.
GTO	Go to memory location specified in the next steps.
END	Used as the last step of a program; sets point of operation location 0000.
PSE	Causes program to pause and x, y, and z to be displayed.
STP	Causes program to stop.
A	Conversion from rectangular to polar coordinates; $\theta \rightarrow y$, $r \rightarrow x$.
H	$x^y \rightarrow x$
I	Natural logarithm of $x \rightarrow x$
J	$e^x \rightarrow x$
L	Used in conjunction with keys M, N, and O for inverse trigonometric functions
M	$\sin x \rightarrow x$
N	$\cos x \rightarrow x$
O	$\tan x \rightarrow x$
K, 4	Common logarithm of $x \rightarrow x$
K, 5	$10^x \rightarrow x$
K, CLX	Clears all numeric registers.

B. Alpha Numeric Mode

The alpha numeric mode is entered by using the FMT step twice and is exited by using FMT once. The mnemonics and their significances in this mode are shown below:

Mnemonic	Character printed
A through 0	A through 0, respectively.
π	P
b	Q
a	R
YTO	S
XTO	T
1/X	U
INT	V
IND	W
YE	X
XFR	Y
XSQ	Z
RUP	@
√‾	√‾
DIV	/
X	*
-	-
+	+
CHS	π
EEX	→
0 through 9	0 through 9, respectively
CLX	,
	.
SFL	=
LBL	$
IFL	?
X<Y	(
PSE	)
X=Y	%
X>Y	"
GTO .	#
CLR	This causes a carriage return
CNT	This causes a space

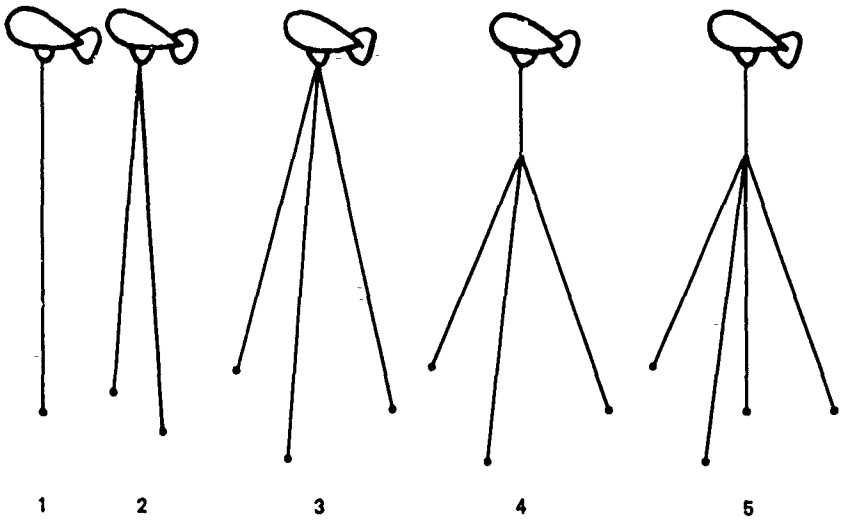
3. COMPUTER PROGRAMS

3.1 Program 76.001 – Tethered Balloon Basic Buoyancy, Ballonet Check, Multiple Tether Cable Configuration

3.1.1 GENERAL DESCRIPTION

This program was developed to assist in the rapid solution of many day-to-day problems involved in estimating which of several stock balloons might be acceptable for a given payload. It is also useful as the first step in the series of programs.

The approach was to permit any one of five typical tethered balloon cable configurations to be handled. These are single, dual, three, four, and five cable configurations as illustrated below.



The program is designed to simply compute the net lifting force at the surface that must be resisted by one or more winches or tie-down points on the ground by subtracting all of the various masses from the gross lift of the balloon. Since no aerodynamic forces are considered, this covers the zero wind case.

Since wind produces additional lift, particularly in the case of aerodynamically shaped balloons, this program is ideal for selecting a minimum balloon size for a given problem. That is, it represents the minimum lift that any configuration will experience.

Also included is a check that the balloon height above ground does not exceed that permitted by the fixed ballonet volume. If it should exceed the allowable excursion, the user is permitted a choice of, (1) accepting the condition which entails a non-rigid balloon on the surface before reelup, (2) requesting the maximum permissable flight altitude for a tight balloon at the surface, or (3) selecting a new altitude.

In the tether cases 2 to 5, additional information on the geometry of the cable layout is also provided.

3.1.2 DEFINITIONS AND DEVELOPMENT: PROGRAM NO. 76.001

A. Wind = 0. Most severe case, that is, minimum lift.

B. Length of cable.

Config. 1: Single tether (N = 1), $\ell = Z_B - Z_S$ = Vert. Height, H

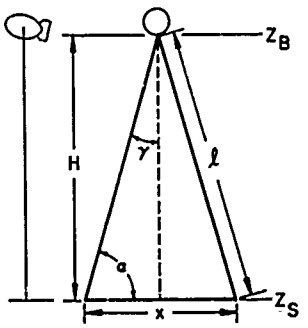
Config. 2: Two tether (N = 2)

Given x, Distance between two Anchor Points

$$\tan \gamma = \frac{x}{2H}$$

$$\alpha = 90 - \gamma$$

$$\ell = H/\sin \alpha$$



Config. 3, 4, and 5 have in common a 3-cable pyramid, all 3 equal in length, the apex lies vertically over the ground zero point, and the 3 anchor points form an equilateral triangle centered at ground zero.

Config. 3: Balloon attached at apex.

Config. 4: Balloon extended above apex by 4th cable, ℓ_e, length of 4th cable, must be entered.

Config. 5: A 5th cable from apex to ground zero is added. (Designated as 5 cables, N=5, even if there is no 4th cable; ℓ_e = 0 as entry)

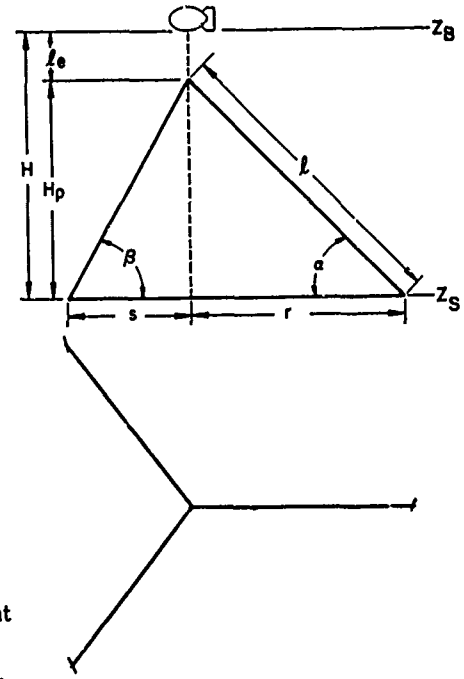
Given α, cable angle at surface

$\ell = \frac{H_p}{\sin \alpha}$, lengths of pyr. cables

$r = \ell \cos \alpha$, radius of ancr. pts.

$s = r/2$

$\beta = \arctan \frac{2 H_p}{r}$, pyr. plane angle at surface.



C. Cable weights:

Allow for each cable to be different size and weight.

Allow for entry of each cable weight after net lift at the balloon is calculated.

Weights entered in lb/1000 ft but these are reduced to lb/ft in program and stored so that the weight of each cable is $\ell \times$ (lb/ft).

D. Basic calculations: V_B = Balloon volume, v = Ballonet volume.

sp. lift at Z_B = Sp Lift at Z = 0, MSL x ρ_{ZB}/ρ_o

Gross lift, $L_G = V_B$ x (Sp. Lift at Z_B)

Net Balloon Lift, $L = L_G - W_B$

Net Balloon lift with Instrument Package = $L - W_I = L_G - W_B - W_I$

Net Balloon lift with Payload = $L - W_I - W_P = L_G - W_B - W_I - W_p$

Net lift on ground = $L_G - W_B - W_I - W_P$ - (sum of all cable weights)

E. Ballonet. Given ballonet volume, v, as entry

(1) By definition: $\rho_d/\rho_o = \frac{V_B - v}{V_B}$, Designed into balloon

(2) Obtain ρ_B/ρ_o from $\frac{\ln \rho/\rho_o}{Z_B} = a_o + a_1 Z_B$

(3) Obtain ρ_S/ρ_o from $\frac{\ln \rho_S/\rho_o}{Z_S} = a_o + a_1 Z_S$

(4) $\rho_B/\rho_S = \rho_B/\rho_o \times \rho_o/\rho_s$

a. If $\rho_B/\rho_S > \rho_d/\rho_S$, balloon flight altitude is lower than the max. it could be flown above Z_s

b. If $\rho_B/\rho_S < \rho_d/\rho_S$, balloon flight altitude is above that permitted by ballonet design for flight starting at Z_S - that is, gas would be lost or must start with slack balloon on the surface to provide full balloon (ballonet empty) at Z_B.

c. If $\rho_B/\rho_S = \rho_d/\rho_S$, exact design flight altitude above Z_S is being used.

d. In program, user is allowed choice if condition b results from the altitude and ballonet size entered.

Choices are: 1. Keep Z_B and accept slack surface condition.

2. Let program compute max. Z_B so that condition c exists.

3. Pick a new Z

For d-2: $\frac{\rho_B}{\rho_S} = \frac{\rho_d}{\rho_S}$

$$\frac{\rho_d}{\rho_o} = \frac{\rho_d}{\rho_S} \times \frac{\rho_S}{\rho_o}$$

Then $Z_B = Z_d = \frac{-a_o - \sqrt{a_o^2 - 4a_1 \ln \rho_d/\rho_o}}{2a_1}$

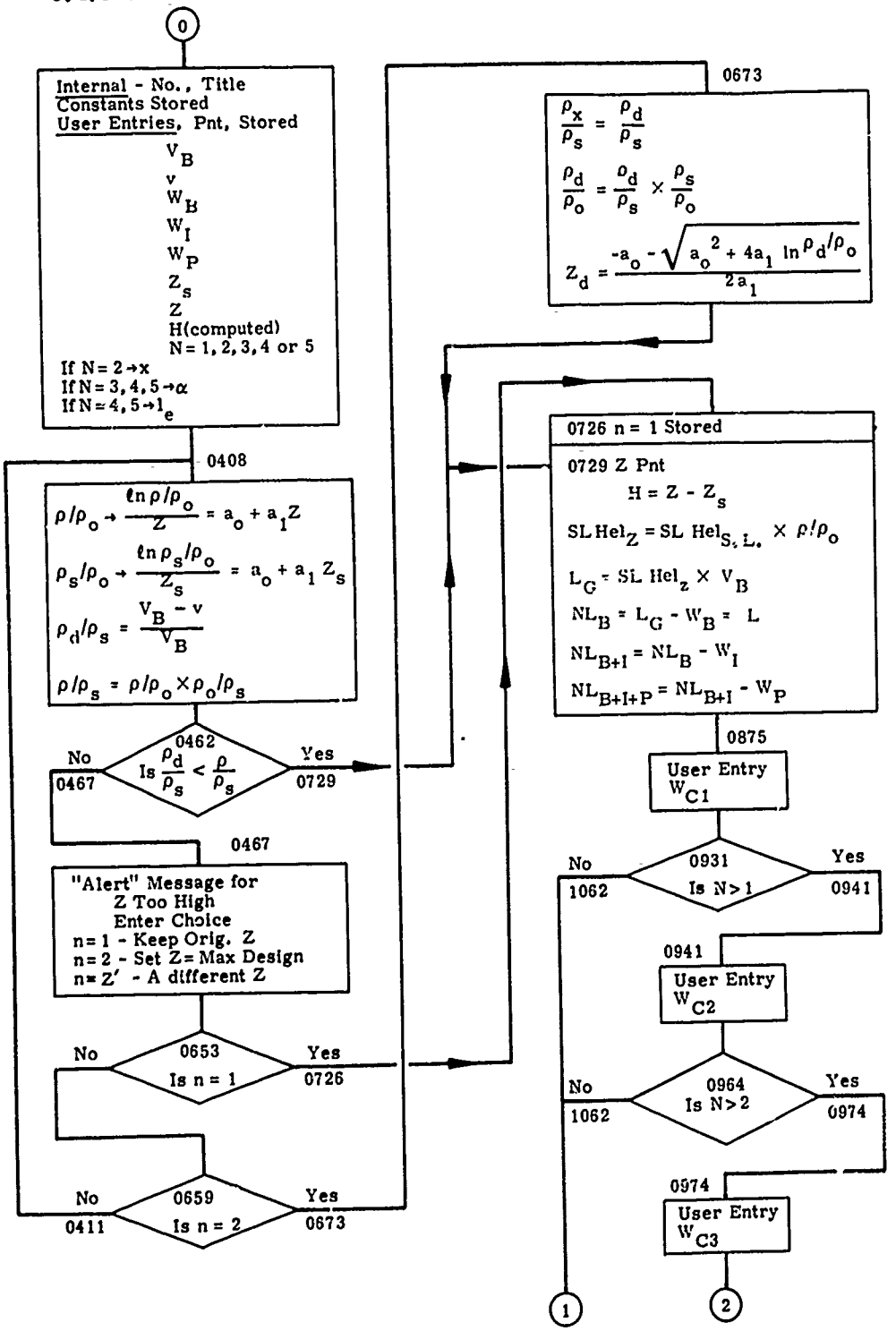
For d-1: Compute amount of inflation on surface

$$\frac{\rho_S}{\rho_B} = \frac{\text{Vol gas at } Z_B}{\text{Vol gas at } Z_S} = \frac{V_B}{\text{Vol gas at } Z_S}$$

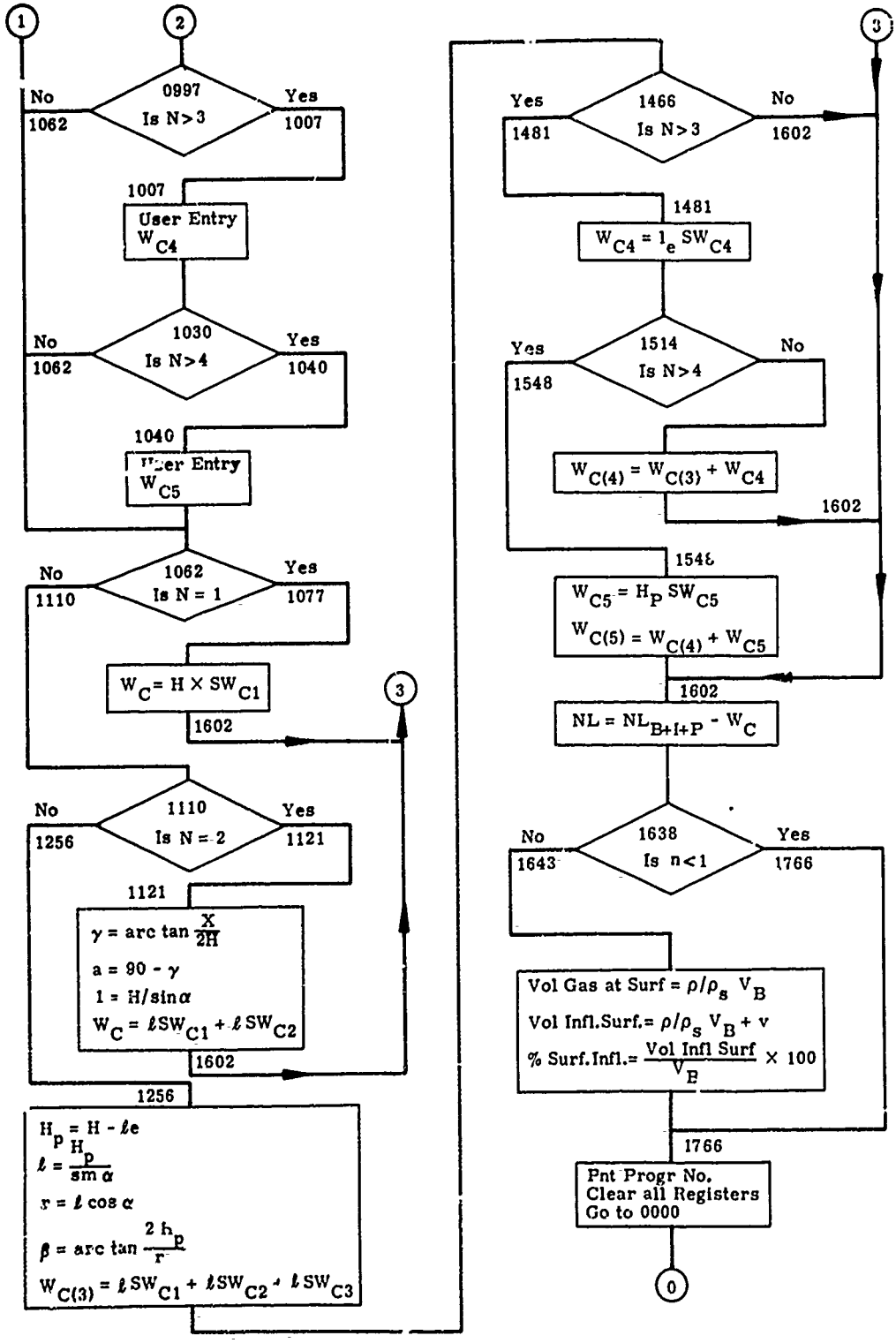
Tot Vol at Z_S = Vol gas at Z_S + v = $V_B \frac{\rho_B}{\rho_S}$ + v

$$\% \text{ fullness at } Z_S = \left(\frac{V_B \rho_B/\rho_S + v}{V_B}\right) 100$$

3.1.3 FLOW CHART

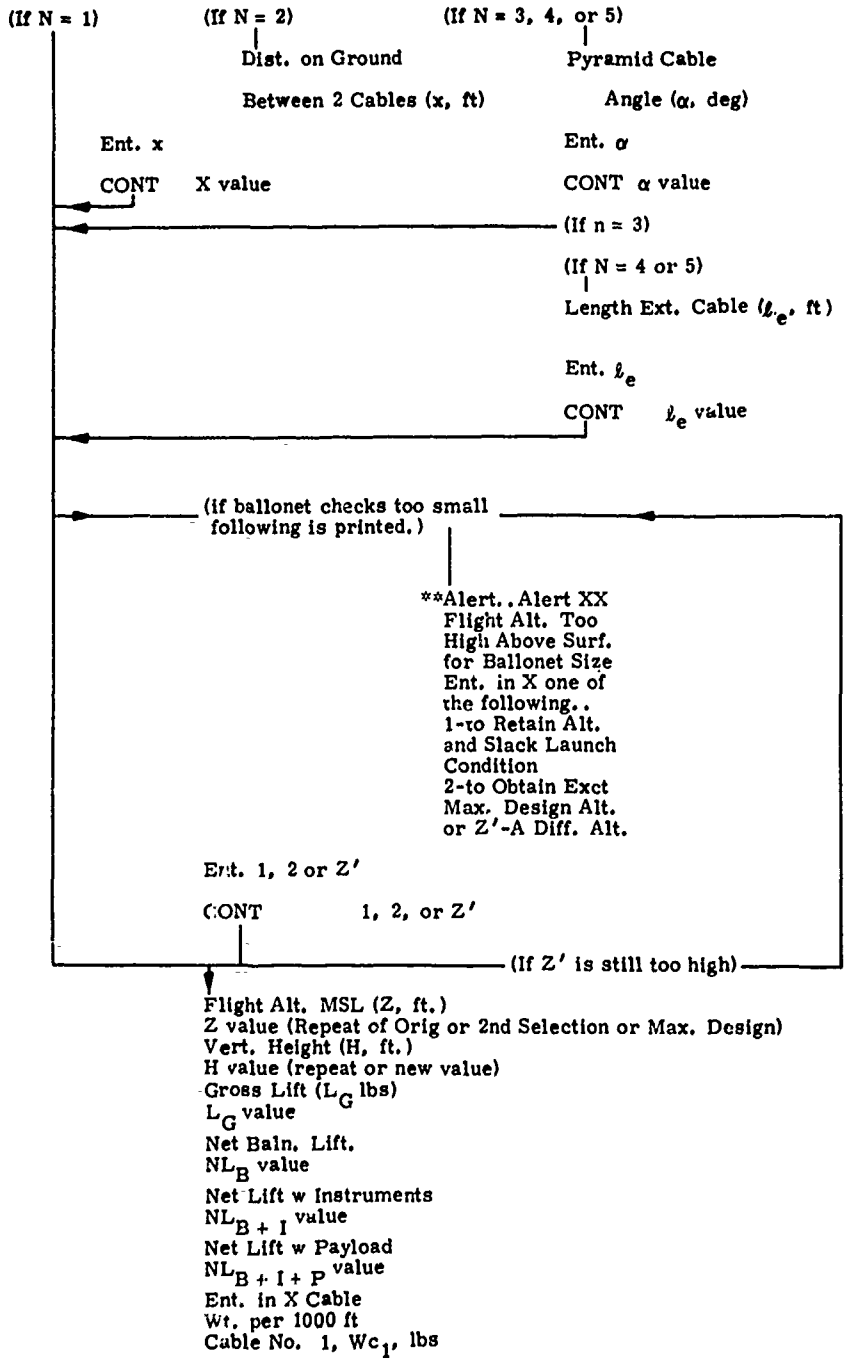


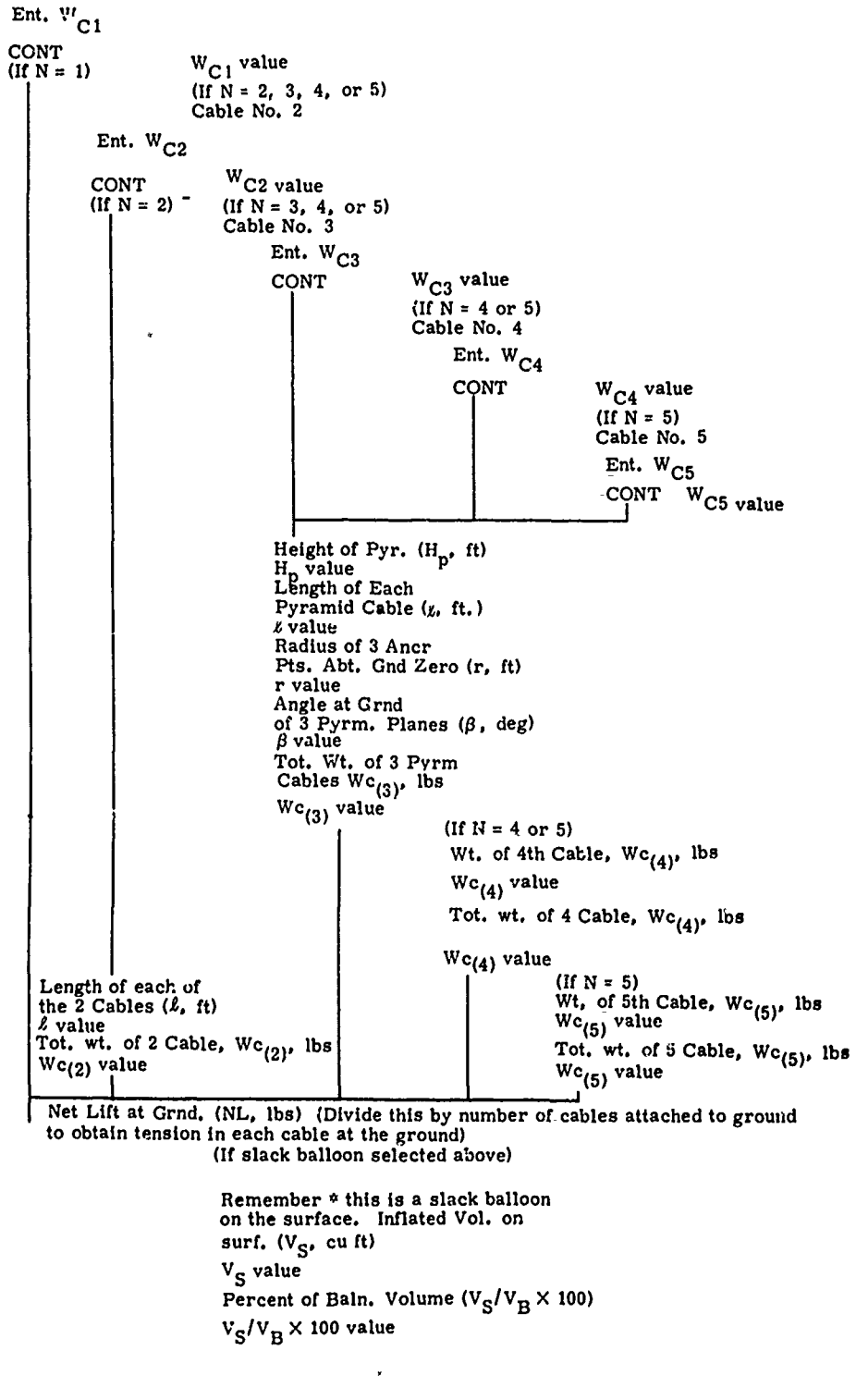
Note: In flow chart, N indicates number of cables, n indicates altitude choice when original altitude entered is too high.


1
2
0997
Is N>3
No
1062
Yes
1007
1007
User Entry
W_{C4}
1030
Is N>4
No
1062
Yes
1040
1040
User Entry
W_{C5}
1062
Is N = 1
No
1110
Yes
1077
$W_C = H \times SW_{C1}$
1602
3
1110
Is N = 2
No
1256
Yes
1121
1121
$\gamma = \arctan \frac{X}{2H}$
$a = 90 - \gamma$
$l = H/\sin\alpha$
$W_C = lSW_{C1} + lSW_{C2}$
1602
1256
$H_p = H - le$
$l = \frac{H_p}{sm\ \alpha}$
$r = l \cos\alpha$
$\beta = \arctan \frac{2\ h_p}{r}$
$W_{C(3)} = lSW_{C1} + lSW_{C2} + lSW_{C3}$
3
1466
Is N>3
Yes
1481
No
1602
1481
$W_{C4} = l_e\ SW_{C4}$
1514
Is N>4
Yes
1548
No
$W_{C(4)} = W_{C(3)} + W_{C4}$
1602
1548
$W_{C5} = H_P\ SW_{C5}$
$W_{C(5)} = W_{C(4)} + W_{C5}$
1602
$NL = NL_{B+I+P} - W_C$
1638
Is n<1
No
1643
Yes
1766
Vol Gas at Surf = $\rho/\rho_s\ V_B$
Vol Infl.Surf.= $\rho/\rho_s\ V_B + v$
% Surf.Infl.= $\frac{\text{Vol Infl Surf}}{V_B} \times 100$
1766
Pnt Progr No.
Clear all Registers
Go to 0000
0

3.1.4 OPERATING INSTRUCTIONS

KEY STROKES	PRINTS
RUN	
END	
FIX 2, 3, ---	(No. of desired decimal places)
CONT	Program No. and Title Enter in X, BALLOON VOL. (V_B, CF)
Ent. V_B	
CONT	V_B value BALLONET VOL. (v, CF)
Ent. v	
CONT	v value BALLOON WEIGHT (W_B, lb)
Ent. W_B	
CONT	W_B value WT. BAL. INSTR. PKG. (W_I, lb)
Ent. W_I	
CONT	W_I value WT. EXP. PAYLOAD (W_P, lb)
Ent. W_P	
CONT	W_P value SURFACE ALT. MSL (Z_S, ft)
Ent. Z_S	
CONT	Z_S value FLIGHT ALT. MSL (Z, ft)
Ent. Z	
CONT	Z value VERT. HEIGHT (H, ft)
	H value NUMBER OF CABLES (N = 1, 2, 3, 4, or 5) (If there is no extension cable between 3 cable pyramid and balloon but there is a cable from apex to ground zero, ENTER/(5).
Ent. N	
CONT	


(If N = 1)
(If N = 2)
(If N = 3, 4, or 5)
Dist. on Ground
Between 2 Cables (x, ft)
Pyramid Cable
Angle (α, deg)
Ent. x
Ent. α
CONT X value
CONT α value
(If n = 3)
(If N = 4 or 5)
Length Ext. Cable (ℓe, ft)
Ent. ℓe
CONT ℓe value
(if ballonet checks too small following is printed.)
**Alert..Alert XX
Flight Alt. Too
High Above Surf.
for Ballonet Size
Ent. in X one of
the following..
1-to Retain Alt.
and Slack Launch
Condition
2-to Obtain Exct
Max. Design Alt.
or Z'-A Diff. Alt.
Ent. 1, 2 or Z'
CONT 1, 2, or Z'
(If Z' is still too high)
Flight Alt. MSL (Z, ft.)
Z value (Repeat of Orig or 2nd Selection or Max. Design)
Vert. Height (H, ft.)
H value (repeat or new value)
Gross Lift (LG lbs)
LG value
Net Baln. Lift.
NLB value
Net Lift w Instruments
NLB + I value
Net Lift w Payload
NLB + I + P value
Ent. in X Cable
Wt. per 1000 ft
Cable No. 1, Wc1, lbs


Ent. W_{C1}
CONT
(If N = 1)
W_{C1} value
(If N = 2, 3, 4, or 5)
Cable No. 2
Ent. W_{C2}
CONT
(If N = 2)
W_{C2} value
(If N = 3, 4, or 5)
Cable No. 3
Ent. W_{C3}
CONT
W_{C3} value
(If N = 4 or 5)
Cable No. 4
Ent. W_{C4}
CONT
W_{C4} value
(If N = 5)
Cable No. 5
Ent. W_{C5}
CONT
W_{C5} value
Height of Pyr. (H_p, ft)
H_p value
Length of Each
Pyramid Cable (ℓ, ft.)
ℓ value
Radius of 3 Ancr
Pts. Abt. Gnd Zero (r, ft)
r value
Angle at Grnd
of 3 Pyrm. Planes (β, deg)
β value
Tot. Wt. of 3 Pyrm
Cables $Wc_{(3)}$, lbs
$Wc_{(3)}$ value
(If N = 4 or 5)
Wt. of 4th Cable, $Wc_{(4)}$, lbs
$Wc_{(4)}$ value
Tot. wt. of 4 Cable, $Wc_{(4)}$, lbs
$Wc_{(4)}$ value
(If N = 5)
Wt, of 5th Cable, $Wc_{(5)}$, lbs
$Wc_{(5)}$ value
Tot. wt. of 5 Cable, $Wc_{(5)}$, lbs
$Wc_{(5)}$ value
Length of each of
the 2 Cables (ℓ, ft)
ℓ value
Tot. wt. of 2 Cable, $Wc_{(2)}$, lbs
$Wc_{(2)}$ value
Net Lift at Grnd. (NL, lbs) (Divide this by number of cables attached to ground to obtain tension in each cable at the ground)
(If slack balloon selected above)
Remember * this is a slack balloon
on the surface. Inflated Vol. on
surf. (V_S, cu ft)
V_S value
Percent of Baln. Volume ($V_S/V_B \times 100$)
$V_S/V_B \times 100$ value

3.1.5 SAMPLE INPUT DATA FORM

Input		76.001
Volume of Balloon	V_B	cu ft
Volume of Ballonet	v	cu ft
Weight of Balloon	W_B	lb
Weight of Instr. Pkg.	W_I	lb
Weight of Payload	W_P	lb
Altitude, Max. or Design	Z_{MAX}	ft, MSL
Altitude of Surface	Z_S	ft, MSL
Number of Cables	N	—
If 2, Distance on ground	X	ft
If 3, 4, or 5, Pyramid Cable Angle	α	deg
If 4 or 5, Length of Ext. Cable	ℓ_e	ft
Cable #1 Weight per 1000 ft		lb
Cable #2 Weight per 1000 ft		lb
Cable #3 Weight per 1000 ft		lb
Cable #4 Weight per 1000 ft		lb
Cable #5 Weight per 1000 ft		lb

3.1.6 PROGRAM 76.001 - BASIC BUOYANCY

STORAGE	
b	a_0
a	a_1
000	1000
001	V_B
002	v
003	W_B
004	W_I
005	W_P
006	Sp.Wt.C-1
007	Sp.Wt.C-2
008	Sp.Wt.C-3
009	Sp.Wt.C-4
010	Sp.Wt.C-5
011	X-2Cable
012	α-2Cable
013	α-Pyr.3
014	ℓ_e-4thC.
015	No. of C.
016	W CABLES
017	NL B+I+P
018	NL
019	$n=1$
020	Sp.L.Hel. S_L
021	Z_S
022	Z
023	$H=Z-Z_S$
024	ρ/ρ_0
025	ρ_S/ρ_0
026	ρ_L/ρ_S
027	$H_P=H-\ell_e$

3.1.6 PROGRAM 76.001 - BASIC BUOYANCY

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0000	CLR	0050	8	0100	L	0150	XTO	0200	FMT	0250	3
0001	FMT	0051	1	0101	L	0151	FMT	0201	FMT	0251	DN
0002	FMT	0052	3	0102	0	0152	STP	0202	YTO	0252	FMT
0003	π	0053	6	0103	0	0153	PNT	0203	1/X	0253	FMT
0004	α	0054	0	0104	N	0154	XTO	0204	α	0254	INT
0005	0	0055	6	0105	CNT	0155	3	0205	F	0255	E
0006	G	0056	CHS	0106	INT	0156	FMT	0206	A	0256	α
0007	α	0057	EEX	0107	0	0157	FMT	0207	C	0257	XTO
0008	A	0058	5	0108	L	0158	IND	0208	E	0258	.
0009	N	0059	CHS	0109	.	0159	XTO	0209	CNT	0259	H
0010	CNT	0060	XTO	0110	FMT	0160	.	0210	A	0260	E
0011	GTO	0061	6	0111	STP	0161	B	0211	L	0261	I
0012	7	0062	0	0112	PNT	0162	A	0212	XTO	0262	G
0013	6	0063	.	0113	XTO	0163	L	0213	.	0263	H
0014	.	0064	0	0114	1	0164	.	0214	M	0264	XTO
0015	0	0065	6	0115	FMT	0165	I	0215	YTO	0265	FMT
0016	0	0066	5	0116	FMT	0166	N	0216	L	0266	PNT
0017	1	0067	9	0117	B	0167	YTO	0217	FMT	0267	FMT
0018	CLR	0068	8	0118	A	0168	XTO	0218	STP	0268	FMT
0019	B	0069	8	0119	L	0169	α	0219	PNT	0269	N
0020	A	0070	XTO	0120	L	0170	.	0220	XTO	0270	1/X
0021	YTO	0071	0	0121	0	0171	π	0221	2	0271	M
0022	I	0072	2	0122	N	0172	K	0222	1	0272	B
0023	C	0073	0	0123	E	0173	G	0223	UP	0273	E
0024	CNT	0074	1	0124	XTO	0174	FMT	0224	FMT	0274	α
0025	B	0075	0	0125	CNT	0175	STP	0225	FMT	0275	CNT
0026	1/X	0076	0	0126	INT	0176	PNT	0226	F	0276	0
0027	0	0077	0	0127	0	0177	XTO	0227	L	0277	F
0028	XFR	0078	XTO	0128	L	0178	4	0228	I	0278	CNT
0029	A	0079	0	0129	.	0179	FMT	0229	G	0279	C
0030	N	0080	FMT	0130	FMT	0180	FMT	0230	H	0280	A
0031	C	0081	FMT	0131	STP	0181	IND	0231	XTO	0281	B
0032	XFR	0082	E	0132	PNT	0182	XTO	0232	CNT	0282	L
0033	FMT	0083	N	0133	XTO	0183	.	0233	A	0283	E
0034	1	0084	XTO	0134	2	0184	E	0234	L	0284	YTO
0035	.	0085	E	0135	FMT	0185	YE	0235	XTO	0285	FMT
0036	7	0086	α	0136	FMT	0186	π	0236	.	0286	STP
0037	7	0087	CNT	0137	B	0187	.	0237	M	0287	PNT
0038	1	0088	I	0138	A	0188	π	0238	YTO	0288	XTO
0039	6	0089	N	0139	L	0189	A	0239	L	0289	1
0040	7	0090	CNT	0140	L	0190	XFR	0240	FMT	0290	5
0041	CHS	0091	YE	0141	0	0191	L	0241	STP	0291	UP
0042	EEX	0092	CLX	0142	0	0192	0	0242	PNT	0292	2
0043	1	0093	-	0143	N	0193	A	0243	XTO	0293	X<Y
0044	0	0094	-	0144	CNT	0194	D	0244	2	0294	0
0045	CHS	0095	-	0145	IND	0195	FMT	0245	2	0295	3
0046	XTO	0096	-	0146	E	0196	STP	0246	XEY	0296	4
0047	α	0097	CLR	0147	I	0197	PNT	0247	-	0297	7
0048	2	0098	B	0148	G	0198	XTO	0248	YTO	0298	X>Y
0049	.	0099	A	0149	H	0199	5	0249	2	0299	0

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0300	4	0350	XFR	0400	L	0450	1	0500	A	0550	IND
0301	0	0351	α	0401	E	0451	UP	0501	B	0551	I
0302	8	0352	A	0402	FMT	0452	XFR	0502	0	0552	N
0303	FMT	0353	M	0403	STP	0453	2	0503	INT	0553	G
0304	FMT	0354	I	0404	XTO	0454	-	0504	E	0554	.
0305	D	0355	D	0405	1	0455	XFR	0505	CNT	0555	.
0306	I	0356	CNT	0406	4	0456	1	0506	YTO	0556	.
0307	YTO	0357	C	0407	PNT	0457	DIV	0507	1/X	0557	CLR
0308	XTO	0358	A	0408	XFR	0458	DN	0508	α	0558	1
0309	.	0359	B	0409	2	0459	XTO	0509	F	0559	-
0310	0	0360	L	0410	2	0460	2	0510	.	0560	XTO
0311	N	0361	E	0411	UP	0461	7	0511	F	0561	0
0312	CNT	0362	CLR	0412	UP	0462	X<Y	0512	0	0562	CNT
0313	G	0363	A	0413	α	0463	0	0513	α	0563	α
0314	α	0364	N	0414	X	0464	7	0514	CNT	0564	E
0315	0	0365	G	0415	b	0465	2	0515	B	0565	XTO
0316	1/X	0366	L	0416	+	0466	9	0516	A	0566	A
0317	N	0367	E	0417	DN	0467	FMT	0517	L	0567	I
0318	D	0368	FMT	0418	X	0468	FMT	0518	L	0568	N
0319	CLR	0369	STP	0419	DN	0469	X	0519	0	0569	CNT
0320	B	0370	PNT	0420	J	0470	X	0520	N	0570	A
0321	E	0371	XTO	0421	XTO	0471	X	0521	E	0571	L
0322	XTO	0372	1	0422	2	0472	A	0522	XTO	0572	XTO
0323	IND	0373	3	0423	4	0473	L	0523	CLR	0573	
0324	E	0374	XFR	0424	XFR	0474	E	0524	YTO	0574	A
0325	E	0375	1	0425	2	0475	α	0525	I	0575	N
0326	N	0376	5	0426	1	0476	XTO	0526	XSQ	0576	D
0327	CNT	0377	UP	0427	UP	0477	X	0527	E	0577	CNT
0328	2	0378	3	0428	UP	0478	X	0528	CLR	0578	YTO
0329	CNT	0379	X=Y	0429	α	0479	CLR	0529	E	0579	L
0330	C	0380	0	0430	X	0480	F	0530	N	0580	A
0331	A	0381	4	0431	b	0481	L	0531	XTO	0581	C
0332	B	0382	0	0432	+	0482	I	0532	.	0582	K
0333	L	0383	8	0433	DN	0483	G	0533	I	0583	CNT
0334	E	0384	FMT	0434	X	0484	H	0534	N	0584	I
0335	YTO	0385	FMT	0435	DN	0485	XTO	0535	CNT	0585	A
0336	FMT	0386	L	0436	J	0486	CNT	0536	YE	0586	1/X
0337	STP	0387	E	0437	XTO	0487	A	0537	CNT	0587	N
0338	PNT	0388	N	0438	2	0488	L	0538	0	0588	C
0339	XTO	0389	G	0439	5	0489	XTO	0539	N	0589	H
0340	1	0390	XTO	0440	1/X	0490	.	0540	E	0590	C
0341	1	0391	H	0441	UP	0491	XTO	0541	CNT	0591	0
0342	GTO	0392	CNT	0442	XFR	0492	0	0542	0	0592	N
0343	0	0393	E	0443	2	0493	0	0543	F	0593	D
0344	4	0394	YE	0444	4	0494	CLR	0544	CLR	0594	I
0345	0	0395	XTO	0445	X	0495	H	0545	F	0595	XTO
0346	8	0396	.	0446	YTO	0496	I	0546	0	0596	I
0347	FMT	0397	C	0447	2	0497	G	0547	L	0597	0
0348	FMT	0398	A	0448	6	0498	H	0548	L	0598	N
0349	π	0399	B	0449	XFR	0499	CNT	0549	0	0599	CLR

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0600	2	0650	PNT	0700	b	0750	UP	0800	UP	0850	-
0601	-	0651	UP	0701	CHS	0751	XFR	0801	XFR	0851	DN
0602	XTO	0652	1	0702	XEY	0752	2	0802	3	0852	FMT
0603	0	0653	X=Y	0703	-	0753	1	0803	-	0853	FMT
0604	CNT	0654	0	0704	a	0754	-	0804	DN	0854	N
0605	0	0655	7	0705	UP	0755	DN	0805	FMT	0855	E
0606	B	0656	2	0706	2	0756	FMT	0806	FMT	0856	XTO
0607	XTO	0657	6	0707	X	0757	FMT	0807	N	0857	CNT
0608	A	0658	2	0708	DN	0758	INT	0808	E	0858	L
0609	I	0659	X=Y	0709	DIV	0759	E	0809	XTO	0859	I
0610	N	0660	0	0710	YTO	0760	a	0810	CNT	0860	F
0611	CNT	0661	6	0711	2	0761	XTO	0811	B	0861	XTO
0612	E	0662	7	0712	2	0762		0812	A	0862	CNT
0613	YE	0663	3	0713	FMT	0763	H	0813	L	0863	IND
0614	C	0664	DN	0714	FMT	0764	E	0814	N	0864	CNT
0615	XTO	0665	XTO	0715	M	0765	I	0815	.	0865	π
0616	M	0666	2	0716	A	0766	G	0816	L	0866	A
0617	A	0667	2	0717	YE	0767	H	0817	I	0867	XFR
0618	YE	0668	GTO	0718	.	0768	XTO	0818	F	0868	L
0619	.	0669	0	0719	FMT	0769	FMT	0819	XTO	0869	D
0620	D	0670	4	0720	CNT	0770	PNT	0820	FMT	0870	FMT
0621	E	0671	1	0721	GTO	0771	XTO	0821	PNT	0871	PNT
0622	YTO	0672	1	0722	0	0772	2	0822	UP	0872	XTO
0623	I	0673	XFR	0723	7	0773	3	0823	XFR	0873	1
0624	G	0674	2	0724	2	0774	XFR	0824	4	0874	7
0625	N	0675	7	0725	9	0775	2	0825	-	0875	FMT
0626	CNT	0676	UP	0726	XTO	0776	0	0826	DN	0876	FMT
0627	A	0677	YTO	0727	1	0777	UP	0827	FMT	0877	E
0628	L	0678	2	0728	9	0778	XFR	0828	FMT	0878	N
0629	XTO	0679	6	0729	XFR	0779	2	0829	N	0879	TO
0630	.	0680	XFR	0730	2	0780	4	0830	E	0880	.
0631	CLR	0681	2	0731	2	0781	X	0831	XTO	0881	I
0632	0	0682	5	0732	FMT	0782	XFR	0832	CNT	0882	N
0633	a	0683	X	0733	FMT	0783	1	0833	L	0883	CNT
0634	CNT	0684	DN	0734	F	0784	X	0834	I	0884	YE
0635	XSQ	0685	XTO	0735	L	0785	DN	0835	F	0885	CNT
0636	-	0686	2	0736	I	0786	FMT	0836	XTO	0886	C
0637	A	0687	4	0737	G	0787	FMT	0837	CNT	0887	A
0638	CNT	0688	I	0738	H	0788	G	0838	IND	0888	B
0639	b	0689	UP	0739	XTO	0789	a	0839	CNT	0889	L
0640	I	0690	4	0740	CNT	0790	0	0840	I	0890	E
0641	F	0691	X	0741	A	0791	YTO	0841	N	0891	CLR
0642	F	0692	a	0742	L	0792	YTO	0842	YTO	0892	IND
0643	.	0693	X	0743	XTO	0793	CNT	0843	XTO	0893	XTO
0644	A	0694	b	0744	.	0794	L	0844	a	0894	.
0645	L	0695	XSQ	0745	M	0795	I	0845	FMT	0895	π
0646	XTO	0696	+	0746	YTO	0796	F	0846	PNT	0896	E
0647	.	0697	DN	0747	L	0797	XTO	0847	UP	0897	a
0648	FMT	0698	r	0748	FMT	0798	FMT	0848	XFR	0898	CNT
0649	STP	0699	UP	0749	PNT	0799	PNT	0849	5	0899	1

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0900	0	0950	0	1000	0	1050	.	1100	B	1150	L
0901	0	0951	.	1001	7	1051	5	1101	L	1151	E
0902	0	0952	2	1002	GTO	1052	FMT	1102	E	1152	CNT
0903	CNT	0953	FMT	1003	1	1053	STP	1103	FMT	1153	0
0904	F	0954	STP	1004	0	1054	PNT	1104	PNT	1154	F
0905	XTO	0955	PNT	1005	6	1055	UP	1105	GTO	1155	CNT
0906	CLR	0956	UP	1006	2	1056	XFR	1106	1	1156	2
0907	C	0957	XFR	1007	FMT	1057	0	1107	6	1157	CNT
0908	A	0958	0	1008	FMT	1058	DIV	1108	0	1158	C
0909	B	0959	DIV	1009	C	1059	YTO	1109	2	1159	A
0910	L	0960	YTO	1010	A	1060	1	1110	2	1160	B
0911	E	0961	7	1011	B	1061	0	1111	X=Y	1161	L
0912	CNT	0962	DN	1012	L	1062	XFR	1112	1	1162	E
0913	N	0963	2	1013	E	1063	1	1113	1	1163	A
0914	0	0964	X<Y	1014	CNT	1064	5	1114	2	1164	XTO
0915	.	0965	0	1015	N	1065	UP	1115	1	1165	CNT
0916	1	0966	9	1016	0	1066	1	1116	GTO	1166	G
0917	FMT	0967	7	1017	.	1067	X=Y	1117	1	1167	a
0918	STP	0968	4	1018	4	1068	1	1118	2	1168	0
0919	PNT	0969	GTO	1019	FMT	1069	0	1119	5	1169	1/X
0920	UP	0970	1	1020	STP	1070	7	1120	6	1170	N
0921	XFR	0971	0	1021	PNT	1071	7	1121	XFR	1171	D
0922	0	0972	6	1022	UP	1072	GTO	1122	1	1172	FMT
0923	DIV	0973	2	1023	XFR	1073	1	1123	1	1173	CNT
0924	YTO	0974	FMT	1024	0	1074	1	1124	UP	1174	PNT
0925	6	0975	FMT	1025	DIV	1075	1	1125	XFR	1175	M
0926	XFR	0976	C	1026	YTO	1076	0	1126	2	1176	UP
0927	1	0977	A	1027	9	1077	XFR	1127	3	1177	XFR
0928	5	0978	B	1028	DN	1078	2	1128	UP	1178	2
0929	UP	0979	L	1029	4	1079	3	1129	2	1179	3
0930	1.	0980	E	1030	X<Y	1080	UP	1130	X	1180	XEY
0931	X<Y	0981	CNT	1031	1	1081	XFR	1131	DN	1181	DIV
0932	0	0982	N	1032	0	1082	6	1132	DIV	1182	DN
0933	9	0983	0	1033	4	1083	X	1133	DN	1183	FMT
0934	4	0984	.	1034	0	1084	YTO	1134	L	1184	FMT
0935	1	0985	3	1035	GTO	1085	1	1135	0	1185	L
0936	GTO	0986	FMT	1036	1	1086	6	1136	UP	1186	E
0937	1	0987	STP	1037	0	1087	DN	1137	9	1187	N
0938	0	0988	PNT	1038	6	1088	FMT	1138	0	1188	G
0939	6	0989	UP	1039	2	1089	FMT	1139	XEY	1189	XTO
0940	2	0990	XFR	1040	FMT	1090	IND	1140	-	1190	H
0941	FMT	0991	0	1041	FMT	1091	XTO	1141	DN	1191	CNT
0942	FMT	0992	DIV	1042	C	1092	.	1142	XTO	1192	0
0943	C	0993	YTO	1043	A	1093	0	1143	1	1193	F
0944	A	0994	S	1044	B	1094	F	1144	2	1194	CNT
0945	B	0995	DN	1045	L	1095	CNT	1145	FMT	1195	E
0946	L	0996	3	1046	E	1096	1	1146	FMT	1196	A
0947	E	0997	X<Y	1047	CNT	1097	CNT	1147	A	1197	C
0948	CNT	0998	1	1048	N	1098	C	1148	N	1198	H
0949	N	0999	0	1049	0	1099	A	1149	G	1199	CLR

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1200	0	1250	PNT	1300	H	1350	α	1400	CNT	1450	M
1201	F	1251	GTO	1301	CNT	1351	π	1401	π	1451	C
1202	CNT	1252	1	1302	0	1352	XTO	1402	XFR	1452	A
1203	XTO	1253	6	1303	F	1353	YTO	1403	α	1453	B
1204	H	1254	0	1304	CNT	1354	.	1404	M	1454	L
1205	E	1255	2	1305	E	1355	A	1405	.	1455	E
1206	CNT	1256	XFR	1306	A	1356	B	1406	π	1456	YTO
1207	2	1257	2	1307	C	1357	XTO	1407	L	1457	FMT
1208	CNT	1258	3	1308	H	1358	.	1408	A	1458	DN
1209	C	1259	UP	1309	CLR	1359	G	1409	N	1459	PNT
1210	A	1260	XFR	1310	π	1360	N	1410	E	1460	UP
1211	B	1261	1	1311	XFR	1361	D	1411	YTO	1461	XFR
1212	L	1262	4	1312	α	1362	.	1412	FMT	1462	1
1213	E	1263	-	1313	A	1363	XSQ	1413	PNT	1463	5
1214	FMT	1264	YTO	1314	M	1364	E	1414	XFR	1464	UP
1215	PNT	1265	2	1315	I	1365	α	1415	6	1465	3
1216	UP	1266	8	1316	D	1366	0	1416	UP	1466	X<Y
1217	UP	1267	XFR	1317	CNT	1367	FMT	1417	XFR	1467	1
1218	XFR	1268	1	1318	C	1368	PNT	1418	7	1468	4
1219	6	1269	3	1319	A	1369	UP	1419	RUP	1469	8
1220	X	1270	M	1320	B	1370	XFR	1420	X	1470	1
1221	XFR	1271	XEY	1321	L	1371	2	1421	RUP	1471	DN
1222	7	1272	FMT	1322	E	1372	8	1422	XEY	1472	YTO
1223	RUP	1273	FMT	1323	FMT	1373	XFY	1423	X	1473	1
1224	X	1274	H	1324	PNT	1374	DIV	1424	RUP	1474	6
1225	DN	1275	E	1325	UP	1375	2	1425	RUP	1475	DN
1226	+	1276	I	1326	XFR	1376	X	1426	+	1476	GTO
1227	DN	1277	G	1327	1	1377	DN	1427	XFR	1477	1
1228	XTO	1278	H	1328	3	1378	L	1428	8	1478	6
1229	1	1279	XTO	1329	N	1379	0	1429	RUP	1479	0
1230	6	1280	CNT	1330	XEY	1380	FMT	1430	X	1480	2
1231	FMT	1281	0	1331	X	1381	FMT	1431	DN	1481	XFR
1232	FMT	1282	F	1332	XEY	1382	A	1432	+	1482	1
1233	XTO	1283	CNT	1333	FMT	1383	N	1433	FMT	1483	4
1234	0	1284	π	1334	FMT	1384	G	1434	FMT	1484	XEY
1235	XTO	1285	XFR	1335	α	1385	L	1435	XTO	1485	XFR
1236	.	1286	α	1336	A	1386	E	1436	0	1486	9
1237	IND	1287	.	1337	D	1387	CNT	1437	XTO	1487	X
1238	XTO	1288	FMT	1338	I	1388	A	1438	.	1488	DN
1239	.	1289	PNT	1339	1/X	1389	XTO	1439	IND	1489	FMT
1240	0	1290	XEY	1340	YTO	1390	CNT	1440	XTO	1490	FMT
1241	F	1291	DIV	1341	CNT	1391	G	1441	.	1491	IND
1242	CNT	1292	DN	1342	0	1392	α	1442	0	1492	XTO
1243	2	1293	FMT	1343	F	1393	N	1443	F	1493	.
1244	CNT	1294	FMT	1344	CNT	1394	D	1444	CNT	1494	0
1245	C	1295	L	1345	3	1395	CLR	1445	3	1495	F
1246	A	1296	E	1346	CNT	1396	0	1446	CNT	1496	CLT
1247	B	1297	N	1347	A	1397	F	1447	π	1497	4
1248	L	1298	G	1348	N	1398	CNT	1448	XFR	1498	XTO
1249	FMT	1299	XTO	1349	C	1399	3	1449	α	1499	H

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1500	CNT	1550	8	1600	FMT	1650	UP	1700	0	1750	F
1501	C	1551	XEY	1601	PNT	1651	XFR	1701	N	1751	CNT
1502	A	1552	CNT	1602	UP	1652	2	1702	CNT	1752	B
1503	B	1553	XFR	1603	XFR	1653	RUP	1703	XTO	1753	A
1504	L	1554	1	1604	1	1654	+	1704	H	1754	L
1505	E	1555	0	1605	7	1655	DN	1705	E	1755	N
1506	FMT	1556	X	1606	XEY	1656	XEY	1706	CNT	1756	.
1507	PNT	1557	DN	1607	-	1657	UP	1707	YTO	1757	INT
1508	+	1558	FMT	1608	DN	1658	DN	1708	1/X	1758	0
1509	XFR	1559	FMT	1609	XTO	1659	DIV	1709	α	1759	L
1510	1	1560	IND	1610	1	1660	1	1710	F	1760	1/X
1511	5	1561	XTO	1611	8	1661	0	1711	A	1761	M
1512	UP	1562	.	1612	FMT	1662	0	1712	C	1762	E
1513	4	1563	0	1613	FMT	1663	X	1713	E	1763	FMT
1514	X<Y	1564	F	1614	N	1664	DN	1714	CLR	1764	PNT
1515	1	1565	CNT	1615	E	1665	XEY	1715	I	1765	PNT
1516	5	1566	5	1616	XTO	1666	FMT	1716	N	1766	FMT
1517	4	1567	XTO	1617	CNT	1667	FMT	1717	F	1767	FMT
1518	8	1568	H	1618	L	1668	α	1718	L	1768	J
1519	RUP	1569	CNT	1619	I	1669	E	1719	A	1769	.
1520	FMT	1570	C	1620	F	1670	M	1720	XTO	1770	B
1521	FMT	1571	A	1621	XTO	1671	E	1721	E	1771	.
1522	XTO	1572	B	1622	CNT	1672	M	1722	D	1772	IND
1523	0	1573	L	1623	-	1673	B	1723	CNT	1773	.
1524	XTO	1574	E	1624	G	1674	E	1724	INT	1774	CNT
1525	.	1575	FMT	1625	α	1675	α	1725	0	1775	CNT
1526	IND	1576	PNT	1626	N	1676	X	1726	L	1776	7
1527	XTO	1577	+	1627	D	1677	XTO	1727	.	1777	6
1528	.	1578	DN	1628	.	1678	H	1728	0	1778	.
1529	0	1579	XTO	1629	-	1679	I	1729	N	1779	0
1530	F	1580	1	1630	FMT	1680	YTO	1730	CLR	1780	0
1531	CNT	1581	6	1631	PNT	1681	CNT	1731	YTO	1781	1
1532	4	1582	FMT	1632	PNT	1682	I	1732	1/X	1782	CLR
1533	CNT	1583	FMT	1633	XFR	1683	YTO	1733	α	1783	CLR
1534	C	1584	XTO	1634	1	1684	A	1734	F	1784	CLR
1535	A	1585	0	1635	9	1685	CNT	1735	.	1785	CLR
1536	B	1586	XTO	1636	UP	1686	YTO	1736	FMT	1786	CLR
1537	L	1587		1637	1	1687	L	1737	PNT	1787	CLR
1538	FMT	1588	IND	1638	X>Y	1688	A	1738	DN	1788	FMT
1539	PNT	1589	XTO	1639	1	1689	C	1739	FMT	1789	K
1540	XTO	1590		1640	7	1690	K	1740	FMT	1790	CLX
1541	1	1591	0	1641	6	1691	CNT	1741	π	1791	GTO
1542	6	1592	F	1642	6	1692	B	1742	E	1792	0
1543	GTO	1593	CNT	1643	XFR	1693	A	1743	α	1793	0
1544	1	1594	5	1644	2	1694	L	1744	C	1794	0
1545	6	1595	CNT	1645	6	1695	L	1745	E	1795	0
1546	0	1596	C	1646	UP	1696	0	1746	N	1796	END
1547	2	1597	A	1647	XFR	1697	0	1747	XTO		
1548	XFR	1598	B	1648	1	1698	N	1748	CNT		
1549	2	1599	L	1649	X	1699	CNT	1749	0		

3.1.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution. For a discussion of the particulars of this problem, see Section 4.

```
PROGRAM #76.001
BASIC BUOYANCY
ENTER IN X.-----
BALLOON VOL.
      30000.000*
BALLONET VOL.
       8000.000*
BALLOON WEIGHT
        725.000*
WT.BAL.INSTR.PKG
        100.000*
WT.EXP.PAYLOAD
        100.000*
SURFACE ALT.MSL
       4000.000*
FLIGHT ALT.MSL
      18000.000*
VERT.HEIGHT
      14000.000
NUMBER OF CABLES
          1.000*
***ALERT**
FLIGHT ALT.TOO
HIGH ABOVE SURF.
FOR BALLONET
SIZE
ENT.IN X ONE OF
FOLLOWING...
1-TO RETAIN ALT.
AND SLACK LAUNCH
CONDITION
2-TO OBTAIN ENGT
MAX.DESIGN ALT.
OR 2-A DIFF.ALT.
          2.000*

MAX.
FLIGHT ALT.MSL
      13906.417
VERT.HEIGHT
       9906.417
GROSS LIFT
       1293.538
NET BALN.LIFT
        568.538
NET LIFT W INSTR
        468.538
NET LIFT W PAYLD
        368.538
ENT.IN X CABLE
WT.PER 1000 FT
CABLE NO.1
         25.000*
WT.OF 1 CABLE
        247.660
NET LIFT -GRND.-
        120.878

J.B.W.  76.001
```

```
PROGRAM #76.001
BASIC BUOYANCY
ENTER IN X,----
BALLOON VOL.
       45000.000*
BALLONET VOL.
       13522.000*
BALLOON WEIGHT
         970.000*
WT.BAL.INSTR.PKG
         150.000*
WT.EXP.PAYLOAD
         100.000*
SURFACE ALT.MSL
        4000.000*
FLIGHT ALT.MSL
       18000.000*
VERT.HEIGHT
       14000.000
NUMBER OF CABLES
           1.000*
***ALERT**
FLIGHT ALT.TOO
HIGH ABOVE SURF.
FOR BALLONET
SIZE
ENT.IN X ONE OF
FOLLOWING...
1-TO RETAIN ALT.
AND SLACK LAUNCH
CONDITION
2-TO OBTAIN EXCT
MAX.DESIGN ALT.
OR Z-A DIFF.ALT.
           2.000-
```

```
MAX.
FLIGHT ALT.MSL
       15323.770
VERT.HEIGHT
       11323.770
GROSS LIFT
        1850.818
NET BALN.LIFT
         880.818
NET LIFT W INSTR
         730.818
NET LIFT W PAYLD
         630.818
ENT.IN X CABLE
WT.PER 1000 FT
CABLE NO.1
          25.000*
WT.OF 1 CABLE
         283.094
NET LIFT -GRND.-
         347.724

J.B.W.  76.001
```

```
PROGRAM #76.001
BASIC BUOYANCY
ENTER IN X,----
BALLOON VOL.
       45000.000*
BALLONET VOL.
       13522.000*
BALLOON WEIGHT
         970.000*
WT.BAL.INSTR.PKG
         150.000*
WT.EXP.PAYLOAD
         100.000*
SURFACE ALT.MSL
        4000.000*
FLIGHT ALT.MSL
       14000.000*
VERT.HEIGHT
       10000.000
NUMBER OF CABLES
           1.000*
FLIGHT ALT.MSL
       14000.000
VERT.HEIGHT
       10000.000
GROSS LIFT
        1934.310
NET BALN.LIFT
         964.310
NET LIFT W INSTR
         814.310
NET LIFT W PAYLD
         714.310
ENT.IN X CABLE
WT.PER 1000 FT
CABLE NO.1
          25.000*
WT.OF 1 CABLE
         250.000
NET LIFT -GRND.-
         464.310

J.B.W.  76.001
```

3.2 Program No. 76.002 — General Tethered Balloons, Trim, Single Altitude, Zero Wind, Optional Matrix

3.2.1 GENERAL DESCRIPTION

The trim of a tethered balloon is associated with the magnitude of several types of forces and their effective points of application relative to the point to which the tether-line is attached. This point of tether-line attachment is called the confluence-point due to its being the confluence of a number of smaller flying-lines leading to attaching points along the balloon's skin.

The forces, (see Figure in Section 3.2.2) acting on a tethered balloon, under zero wind conditions are the gross lift and the weight of the balloon and its hardware; their net effect being opposed by tension in the tether cable.

In Section 3.2.2, the derivation of an equation adaptable to use in a simple computer is shown. It essentially states that the net rotational moment about the confluence-point must be zero. The program will compute the lift force from the volume and altitude entered and then solve a simple equation for the trim angle-of-attack.

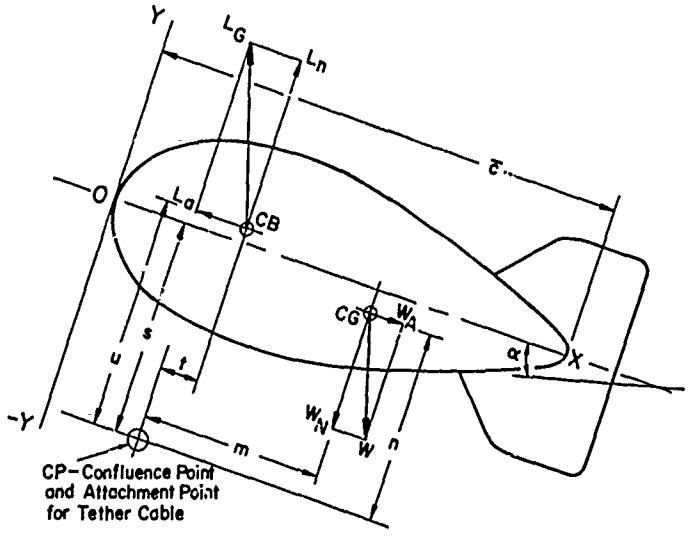
An optional feature is a matrix whereby four dimensions relating the center-of-gravity and center-of-buoyancy positions are made to vary automatically with a trim angle solution for every combination of the four variables.

3.2.2 DEVELOPMENT OF PROGRAM AND EQUATIONS

This case is concerned with any tethered balloon under zero wind conditions.

A. The object of the program is to determine the trim angle of the balloon. The tether cable is connected to the system at the confluence point of the multiple flying-lines attached to the balloon's skin. Hence at trim:

Σ Moments at Confluence Point = 0



Consider Positive Moment Clockwise

If $L_a = L_G \sin\alpha$

$L_n = L_G \cos\alpha$

$W_A = W \sin\alpha$

$W_N = W \cos\alpha$

Sum of the moments:

(1) $m W_N + n W_A - u L_a - t L_n = 0$

(2) $m W \cos\alpha + n W \sin\alpha - u L_G \sin\alpha - t L_G \cos\alpha = 0$

(3) $m W - t L_G + n W \tan\alpha - u L_G \cos\alpha = 0$

(4) $m W - t L_G = \tan\alpha\,(u L_G - n W)$

(5) $\alpha = \arctan \dfrac{m W - t L_G}{u L_G - n W}$

B. Dimensions, m, n, t, and u are needed within program but are included by providing the locations of the C.P., C.G., and C.B. on the x-y grid defined above, that is,

X^{CP}	- Pos. Value	Y_{CG}	- Neg. Value
Y^{CP}	- Neg. Value	X_{CB}	- Pos. Value
X_{CG}	- Pos. Value	Y_{CB}	- Pos. Value

Then,

$$m = X_{CG} - X^{CP} \qquad t = X_{CB} - X^{CP}$$
$$n = Y_{CG} - Y^{CP} \qquad u = Y_{CB} - Y^{CP}$$

C. To provide an optional matrix of variations in m, n, t, and u to indicate an optimum combination in design problem, the program is set up so that after first computation each in turn will be incremented to a larger value by a desired amount, say 0.1 ft, any number of times up to a limit. To handle this, inputs are:

Δm	- m Increment	Δt	- t Increment
$n\Delta m$	- Number of m Increments	$N\Delta t$	- Number of t Increments
Δn	- n Increment	Δu	- u Increment
$N\Delta n$	- Number of n Increments	$N\Delta u$	- Number of u Increments

This suggests that when running the matrix, values of CG, CB, and CP locations should be entered to produce the smallest reasonable starting values for m, n, t, and u in order to bracket useable conditions.

D. To calculate lift for a given volume of balloon at any altitude, using helium. The density ratio may be obtained by use of the relationship

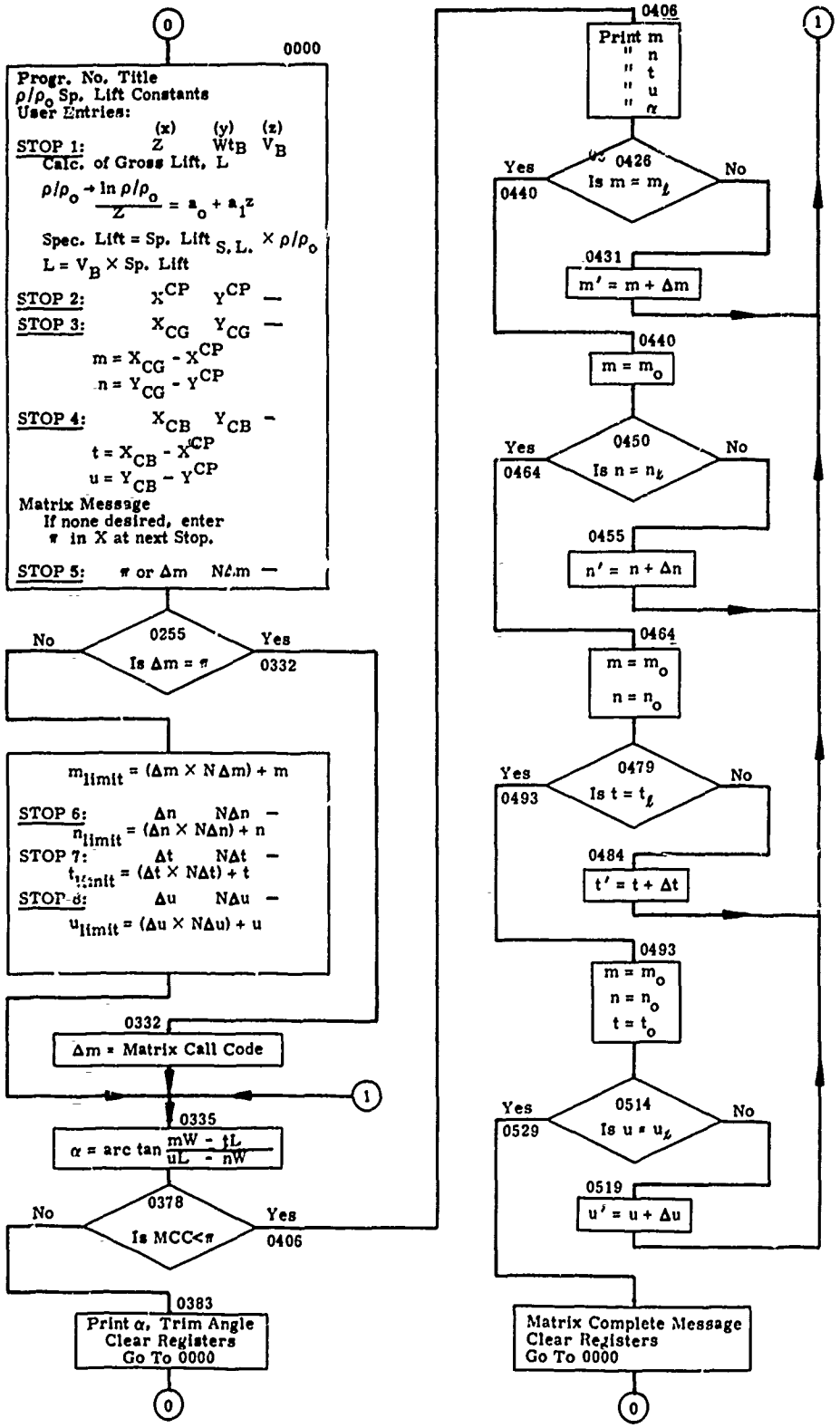
$$\frac{\ln \rho/\rho_o}{Z} = a_o + a_1 Z$$

where

Z = altitude, Ft. MSL
$a_1 = -1.7772^{-10}$
$a_o = -2.81361^{-5}$

The specific lift of helium, standard conditions at sea level .06599 lbs/ft^2.
Specific lift at altitude = $.06599\ \rho/\rho_o$
Gross lift, $L_G = V_B$ x (Specific lift)

3.2.3 FLOW CHART

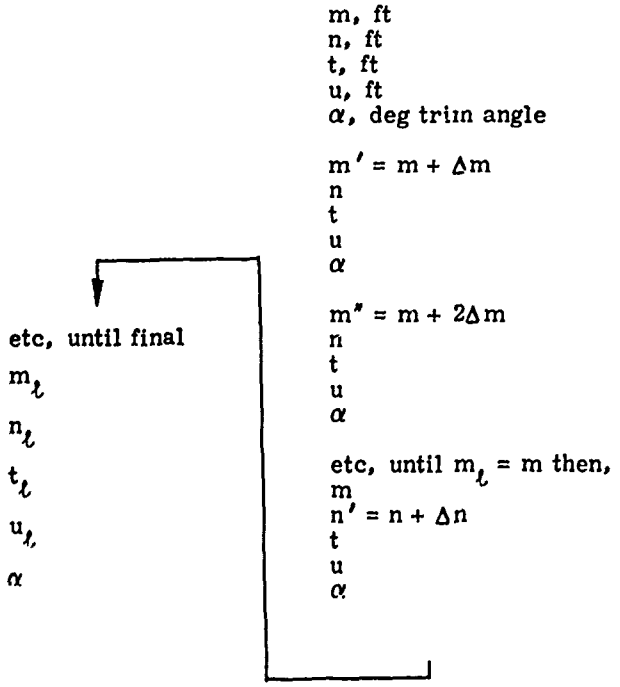


3.2.4 OPERATING INSTRUCTIONS

KEY STROKES		ENTRIES		PRINTS
RUN				
END				
FIX, 2, 3, ----				(No. of decimal places desired)
CONT	(X)	(Y)	(Z)	Program No. & Title
Stop 1, Enter:	Z	W_B	V_B	
CONT				V_B, Balloon Volume CF W_B, Balloon Weight, lb Z, Altitude, ft MSL L_G, Gross Lift, lb
Stop 2, Enter:	X^{CP}	Y^{CP}	-	
CONT				X^{CP}, Confl. Point X, ft Y^{CP}, Confl. Point Y, ft
Stop 3, Enter:	X_{CG}	Y_{CG}	-	
CONT				X_{CG}, Center of Gravity X, ft Y_{CG}, Center of Gravity Y, ft
Stop 4, Enter:	X_{CB}	Y_{CB}	-	
CONT				X_{CB}, Center of Buoyancy X, ft Y_{CB}, Center of Buoyancy Y, ft m, ft n, ft t, ft u, ft Ent. ¶ in X if no matrix calculations are desired.
Stop 5, Enter:	¶	-	-	(If no matrix requested.) Trim angle, α Value of trim angle
or				
Stop 5, Enter:	Δm	$N\Delta m$	-	
CONT				Δm, Increments of Δm, ft $N\Delta m$, No. of Increments m_ℓ, Limiting Value of m, ft

Stop 6, Enter:	Δn	$N\Delta n$	-
CONT			Δn Increments of Δn ft $N\Delta n$ No. of Increments n_ℓ Limiting values of n, ft
Stop 7, Enter:	Δt	$N\Delta t$	-
CONT			Δt, Increments of Δt, ft $N\Delta t$, No. of Increments t_ℓ, Limiting value of t, ft
Stop 8, Enter:	Δu	$N\Delta u$	-
CONT			Δu, Increments of Δu, ft $N\Delta u$, No. of Increments u_ℓ Limiting value of u, ft

Program then proceeds to calculate all combinations of m, n, t and u in matrix beginning with initial values obtained from entries at Stop Nos. 2, 3, and 4.



3.2.5. SAMPLE INPUT DATA FORM

	INPUT					76.002, 76.003, 7 .004, and 76.005	
				76.003, 76.004, 76.005 EXTRA WEIGHT TABLE		76.003 and 76.005 WIND PROFILE*	
	Balloon Volume	V_B	cu ft	W_1	lb	No. 1	1
	Ballonet Volume	v	cu ft	Y_1	ft	Z_{MAX}, ft MSL	
	Balloon Weight	W_B	lb	X_1	ft	Wind, knots	
	Hull Length	$\bar{c}$	ft	W_2		No. 2	2
(1)	Location of Confluence Pt.	Y^{CP}	ft	Y_2		Z_2	
		X^{CP}	ft	X_2		$Wind_2$	
(1)	Location of Center of Gravity	Y^{CG}	ft	W_3		No. 3	3
		X^{CG}	ft	Y_3		Z_3	
(2)	Location of Center of Buoyancy	Y^{CB}	ft	X_3		$Wind_3$	
		X^{CB}	ft	W_4		No. 4	4
(3)	Location of Aero Reference Center	Y^{ARC}	ft	Y_4		Z_4	
		X^{ARC}	ft	X_4		$Wind_4$	
	Altitude, Max	Z_M	ft	W_5		No. 5	5
	Altitude, Surf	Z_S	ft	Y_5		Z_5	
	Increment of Alt	ΔZ	ft	X_5		$Wind_5$	
(3)	$dC_L/d\alpha$	a		W_6		No. 6	6
(3)	C_{D_O}	b		Y_6		Z_6	
(3)	$dC_D/d\alpha^2$	c		X_6		$Wind_6$	
(3)	C_M TABLE*			W_7		No. 7	7
	NO. 1	1		Y_7		Z_7	
	α_1	0	deg	X_7		$Wind_7$	
	C_{M1}			W_8		No. 8	8
	NO. 2	2		Y_8		Z_8	
	α_2		deg	X_8		$Wind_8$	
	C_{M2}			W_9		No. 9	9
	NO. 3	3		Y_9		Z_9	
	α_3		deg	X_9		$Wind_9$	
	C_{M3}			W_{10}		No. 10	10
	NO. 4	4		Y_{10}		Z_{10}	
	α_4		deg	X_{10}		$Wind_{10}$	
	C_{M4}			W_{11}		No. 11	11
	NO. 5	5		Y_{11}		Z_{11}	
	α_5		deg	X_{11}		$Wind_{11}$	
	C_{M5}			W_{12}		No. 12	12
	NO. 6	6		Y_{12}		Z_{12}	
	α_6		deg	X_{12}		$Wind_{12}$	
	C_{M6}			W_{13}		No. 13	13
	NO. 7	7		Y_{13}		Z_{13}	
	α_7		deg	X_{13}		$Wind_{13}$	
	C_{M7}						

(1) See Note 76.005
(2) Req'd for 76.002 and 76.003
(3) Req'd for 76.003 only
* A minimum of two points must be used, a maximum of seven points may be used. First point must be for $\alpha = 0°$

Any number of extra weights may be used. One entry [illegible] be [illegible] are at confluence point [illegible]
$Y = Y^{CP}$
$X = X^{CP}$

A minimum of 2 points must be used and a maximum of 13 may be used. First must be [illegible] at last must be [illegible] 76.004 requires [illegible]

3.2.6 PROGRAM 76.002 - TRIM, GENERAL BALLOON, WIND = 0

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0000	--CLR	0050	--XTO	0100	-- 6	0150	-- 9	0200	--PNT	0250	-- UP
0001	--FNT	0051	-- 0	0101	--RUP	0151	-- -	0201	-- DN	0251	--STP
0002	--FNT	0052	-- 1	0102	--XEY	0152	--YTO	0202	--PNT	0252	-- UP
0003	-- π	0053	-- 3	0103	-- X	0153	-- 1	0203	-- DN	0253	-- π
0004	-- α	0054	-- 2	0104	-- UP	0154	--YTO	0204	--PNT	0254	--X=Y
0005	-- 0	0055	-- .	0105	--XFR	0155	-- 3	0205	--PNT	0255	-- 0
0006	-- G	0056	-- 8	0106	-- 1	0156	-- 1	0206	--FNT	0256	-- 3
0007	-- .	0057	-- 1	0107	-- 2	0157	--XFR	0207	--FNT	0257	-- 3
0008	--GTO	0058	-- 3	0108	--RUP	0158	-- 8	0208	-- E	0258	-- 2
0009	-- 7	0059	-- 6	0109	-- +	0159	--RUP	0209	-- H	0259	-- DN
0010	-- 6	0060	-- 1	0110	-- DN	0160	--XEY	0210	--XTO	0260	--PNT
0011	-- .	0061	--CHS	0111	--XEY	0161	-- -	0211	-- .	0261	--XTO
0012	-- 0	0062	--EEX	0112	-- X	0162	--YTO	0212	--CHS	0262	-- 4
0013	-- 0	0063	-- 5	0113	-- DN	0163	-- 0	0213	--CNT	0263	--XEY
0014	-- 2	0064	--CHS	0114	-- J	0164	--YTO	0214	-- I	0264	--PNT
0015	--CLR	0065	--XTO	0115	-- UP	0165	-- 0	0215	-- N	0265	-- X
0016	--XTO	0066	-- 0	0116	--XFR	0166	-- 3	0216	--CNT	0266	--XFR
0017	-- α	0067	-- 1	0117	-- 1	0167	-- 0	0217	-- YE	0267	-- 0
0018	-- I	0068	-- 2	0118	-- 4	0168	-- 4	0218	--CNT	0268	-- +
0019	-- M	0069	-- .	0119	-- X	0169	-- UP	0219	-- I	0269	--YTO
0020	--CLX	0070	-- 0	0120	--XFR	0170	-- UP	0220	-- F	0270	-- 5
0021	-- G	0071	-- 6	0121	-- 1	0171	--STP	0221	--CNT	0271	-- DN
0022	-- E	0072	-- 5	0122	-- 5	0172	--PNT	0222	-- N	0272	--PNT
0023	-- N	0073	-- 9	0123	-- X	0173	--XEY	0223	-- O	0273	-- 6
0024	-- .	0074	-- 9	0124	--YTO	0174	--PNT	0224	-- M	0274	-- UP
0025	-- B	0075	--XTO	0125	-- b	0175	--PNT	0225	-- A	0275	-- UP
0026	-- A	0076	-- 0	0126	-- DN	0176	-- UP	0226	--XTO	0276	--STP
0027	-- L	0077	-- 1	0127	--PNT	0177	--XFR	0227	-- α	0277	--PNT
0028	-- L	0078	-- 4	0128	--PNT	0178	-- 9	0228	-- I	0278	--XTO
0029	-- O	0079	-- 1	0129	--PNT	0179	-- -	0229	-- YE	0279	-- 6
0030	-- O	0080	-- UP	0130	-- 2	0180	--YTO	0230	--CNT	0280	--XEY
0031	-- N	0081	-- UP	0131	-- UP	0181	-- 3	0231	-- C	0281	--PNT
0032	--IND	0082	--STP	0132	-- UP	0182	--YTO	0232	-- A	0282	-- X
0033	-- I	0083	--RUP	0133	--STP	0183	-- 3	0233	-- L	0283	--XFR
0034	-- N	0084	--PNT	0134	--YTO	0184	-- 3	0234	-- C	0284	-- 1
0035	-- D	0085	--XTO	0135	-- 9	0185	--XFR	0235	-- .	0285	-- +
0036	--SFL	0086	-- 1	0136	--PNT	0186	-- 8	0236	-- A	0286	--YTO
0037	-- 0	0087	-- 5	0137	--XTO	0187	--RUP	0237	-- α	0287	-- 7
0038	--FNT	0088	--RUP	0138	-- 8	0188	--XEY	0238	-- E	0288	-- DN
0039	-- 1	0089	--PNT	0139	--XEY	0189	-- -	0239	--CLR	0289	--PNT
0040	-- .	0090	--XTO	0140	--PNT	0190	--YTO	0240	-- D	0290	-- 7
0041	-- 7	0091	-- α	0141	-- 3	0191	-- 2	0241	-- E	0291	-- UP
0042	-- 7	0092	--XFR	0142	-- UP	0192	--YTO	0242	--YTO	0292	-- UP
0043	-- 7	0093	-- 1	0143	-- UP	0193	-- 3	0243	-- I	0293	--STP
0044	-- 2	0094	-- 3	0144	--STP	0194	-- 2	0244	-- α	0294	--PNT
0045	--CHS	0095	--XEY	0145	--PNT	0195	--XFR	0245	-- E	0295	--XTO
0046	--EEX	0096	--RUP	0146	--XEY	0196	-- 0	0246	-- D	0296	-- 8
0047	-- 1	0097	--PNT	0147	--PNT	0197	--PNT	0247	--FNT	0297	--XEY
0048	-- 0	0098	--XTO	0148	-- UP	0198	--XFR	0248	-- 5	0298	--PNT
0049	--CHS	0099	-- 1	0149	--XFR	0199	-- 1	0249	-- UP	0299	-- X

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0300	--%FR	0350	-- 2	0400	--CLX	0450	--%=Y	0500	-- 1	0550	-- 0
0301	-- 2	0351	-- X	0401	--GTO	0451	-- 0	0501	--XTO	0551	-- 0
0302	-- -	0352	--XFR	0402	-- 0	0452	-- 4	0502	-- 1	0552	-- 0
0303	--YTO	0353	-- 3	0403	-- 0	0453	-- 6	0503	--XFR	0553	-- 0
0304	-- 9	0354	--RUP	0404	-- 0	0454	-- 4	0504	-- 3	0554	--END
0305	-- DN	0355	--RUP	0405	-- 0	0455	--XFR	0505	-- 2		
0306	--PNT	0356	-- -	0406	--XFR	0456	-- 6	0506	--XTO		
0307	-- 8	0357	-- 6	0407	-- 0	0457	-- +	0507	-- 2		
0308	-- UP	0358	--RUP	0408	--PNT	0458	--YTO	0508	--XFR		
0309	-- UP	0359	-- X	0409	-- UP	0459	-- 1	0509	-- 3		
0310	--STF	0360	--%FR	0410	--XFR	0460	--GTO	0510	-- UP		
0311	--PNT	0361	-- 3	0411	-- 1	0461	-- 3	0511	--XFR		
0312	--XTO	0362	-- 4	0412	--PNT	0462	-- 3	0512	-- 1		
0313	-- 1	0363	-- -	0413	--XFR	0463	-- 5	0513	-- 1		
0314	-- 0	0364	-- DN	0414	-- 2	0464	--XFR	0514	--X=Y		
0315	--XEY	0365	--DIV	0415	--PNT	0465	-- 3	0515	-- 0		
0316	--PNT	0366	-- DN	0416	--XFR	0466	-- 0	0516	-- 5		
0317	-- X	0367	-- L	0417	-- 3	0467	--XTO	0517	-- 2		
0318	--XFR	0368	-- 0	0418	--PNT	0468	-- 0	0518	-- 9		
0319	-- 3	0369	--XTO	0419	--XFR	0469	--XFR	0519	--XFR		
0320	-- +	0370	-- 1	0420	-- 1	0470	-- 3	0520	-- 1		
0321	--YTO	0371	-- 7	0421	-- 7	0471	-- 1	0521	-- 0		
0322	-- 1	0372	-- UP	0422	--PNT	0472	--XTO	0522	-- +		
0323	-- 1	0373	--XFR	0423	--PNT	0473	-- 1	0523	--YTO		
0324	-- DN	0374	-- 2	0424	--XFR	0474	--XFR	0524	-- 3		
0325	--PNT	0375	-- 9	0425	-- 5	0475	-- 2	0525	--GTO		
0326	--PNT	0376	-- UP	0426	--X=Y	0476	-- UP	0526	-- 3		
0327	--PNT	0377	-- π	0427	-- 0	0477	--XFR	0527	-- 3		
0328	--GTO	0378	--X>Y	0428	-- 4	0478	-- 9	0528	-- 5		
0329	-- 3	0379	-- 0	0429	-- 4	0479	--X=Y	0529	--FIX		
0330	-- 3	0380	-- 4	0430	-- 0	0480	-- 0	0530	--FNT		
0331	-- 5	0381	-- 0	0431	--XFR	0481	-- 4	0531	-- M		
0332	--XTO	0382	-- 6	0432	-- 4	0482	-- 9	0532	-- A		
0333	-- 2	0383	--RUP	0433	-- +	0483	-- 3	0533	--XTO		
0334	-- 9	0384	--FNT	0434	--YTO	0484	--XFR	0534	-- α		
0335	--XFR	0385	--FNT	0435	-- 0	0485	-- 8	0535	-- I		
0336	-- 0	0386	--XTO	0436	--GTO	0486	-- +	0536	-- YE		
0337	-- UP	0387	-- α	0437	-- 3	0487	--YTO	0537	--CNT		
0338	-- α	0388	-- I	0438	-- 3	0488	-- 2	0538	-- C		
0339	-- X	0389	-- M	0439	-- 5	0489	--GTO	0539	-- 0		
0340	-- UP	0390	--CNT	0440	--XFR	0490	-- 3	0540	-- M		
0341	--XFR	0391	-- A	0441	-- 3	0491	-- 3	0541	-- π		
0342	-- 1	0392	-- N	0442	-- 0	0492	-- 5	0542	-- L		
0343	-- X	0393	-- G	0443	--XTO	0493	--XFR	0543	-- E		
0344	--YTO	0394	-- L	0444	-- 0	0494	-- 3	0544	--XTO		
0345	-- 3	0395	-- E	0445	--XFR	0495	-- 0	0545	-- E		
0346	-- 4	0396	--FNT	0446	-- 1	0496	--XTO	0546	--FNT		
0347	-- 6	0397	--FNT	0447	-- UP	0497	-- 0	0547	-- K		
0348	--XEY	0398	--FNT	0448	--XFR	0498	--XFR	0548	--CLX		
0349	--XFR	0399	-- K	0449	-- 7	0499	-- 3	0549	--GTO		

STORAGE	
b	L_c
a	W_{to}
000	m
001	n
002	t
003	u
004	Δm
005	m_{limit}
006	Δn
007	n_{limit}
008	Δt
009	t_{limit}
010	Δu
011	u_{limit}
012	a_c
013	w_i
014	Sp. Lift acc.
015	$\sqrt{\sigma}$
016	Z
017	w
018	$X^{c.p.}$
019	$y^{c.p.}$
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021	
022	
023	
024	
025	
026	
027	
028	
029	π matrix const.
030	m_c
031	n_c
032	t_c
033	u_c
034	F, m_c
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3.2.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution. The left column shows input and output printouts without the matrix solution. The center and right columns show, for the same starting input figures, the first few and last few of the matrix solutions called for by the initial definitions of matrix size, Δm, NΔm, etc.

```
PROG.#76.002
TRIM;GEN.BALLOON
WIND=0
        45000.00
         1000.00
         5000.00
         2568.41


           26.60
          -31.90
           55.00*
           -3.00
           30.00*
            0.20

           28.40
           28.90
            3.40
           32.10

ENT.# IN X IF NO
MATRIX CALC.ARE
DESIRED
TRIM ANGLE
           20.17
```

```
PROG.#76.002
TRIM;GEN.BALLOON
WIND=0
        45000.00
         1000.00
         5000.00
         2568.41


           26.60
          -31.90
           55.00*
           -3.00
           30.00*
            0.20

           28.40
           28.90
            3.40
           32.10

ENT.# IN X IF NO
MATRIX CALC.ARE
DESIRED
            5.00
            2.00
           38.40
            1.00*
            2.00
           30.90
            7.50*
            2.00
           18.40
            0.25*
            2.00
           32.60


           28.40
           28.90
            3.40
           32.10
           20.17

           33.40
           28.90
            3.40
           32.10
           24.73
```

```
           38.40
           28.90
            3.40
           32.10
           28.99

           28.40
           29.90
            3.40
           32.10
           20.52

           33.40
           29.90
            3.40
           32.10
           25.15

           38.40
           29.90
            3.40
           32.10
           29.45

           28.40
           30.90
            3.40
           32.10
           20.88


           33.40
           30.90
           18.40
           32.60
          -14.70

           38.40
           30.90
           18.40
           32.60
           -9.52

MATRIX COMPLETE
PROG.#76.002
TRIM;GEN.BALLOON
WIND=0
```

3.3 Program No. 76.003 — General Tethered Balloon, Trim, Variable Altitude and Wind

3.3.1 GENERAL DESCRIPTION

The trim of a tethered balloon is associated with the magnitude of several types of forces and their effective points of application relative to the point to which the tether-line is attached. This point of tether-line attachment is called the confluence-point due to its being the confluence of a number of smaller flying-lines leading to attaching points along the balloon's skin.

The forces acting on a tethered balloon, (Figure in Section 3.3.2) are the gross lift, the weight of the balloon and its hardware, and those aerodynamic forces and moments generated by the action of the wind. Since trim in the vertical sense is of principal interest in loading or in early design of a tethered system, the lift, drag, and pitching-moment were the only aerodynamic parameters considered.

In Section 3.3.2, the derivation of an equation adaptable to use in a simple computer is shown. It essentially states that the net rotational moment about the confluence-point must be zero. Program 76.002 is for the condition of a single altitude where the wind is zero and therefore considers only the lift due to helium buoyancy and the weight of the balloon. Program 76.003 considers all parameters, including a zero-wind input, and in addition permits application of any extra masses at any location on the balloon. It calculates the gross-lift at any maximum altitude selected assuming that the balloon is completely filled with helium. At incrementally decreasing altitudes, this lift remains constant. Since a wind-profile from the maximum altitude to the surface altitude, is part of the user entries, the aerodynamic parameters vary with the wind magnitude and atmospheric density.

Unlike Program Nos. 76.004 and 76.005, the parameters completely defining the aerodynamics and the possible movement of the centers of buoyancy or gravity with trim-angle or ballonet condition of most balloon designs are not completely known. Accordingly, all defining parameters are left as user inputs and the reference centers left fixed for all flight conditions. For example, a fixed aerodynamic-reference-center for application of a pitching-moment coefficient is utilized here (In 76.004 and 5, the more convenient concept of a variable center-of-pressure eliminating pitching-moment was possible.)

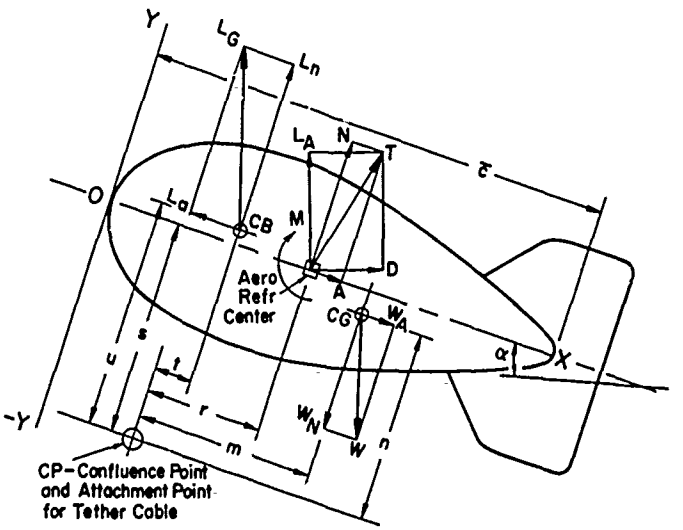
The ballonet fullness, which depends on relationships between maximum and surface altitudes, was not needed or considered here. Use of Program No. 76.001 is recommended to first check that the capacity of the balloon's ballonet is not exceeded by any proposed altitude excursion.

3.3.2 DEVELOPMENT OF PROGRAM AND EQUATIONS

This case is concerned with any tethered balloon at any altitude or wind condition. Knowledge of aerodynamic coefficients, C_L-C_D-C_M, are presumed.

A. The object of the program is to determine the trim conditions of the balloon and the total force and its angle which must be resisted by the tether-cable. The tether cable is connected to the system at the confluence-point of the multiple flying-lines attached to the balloon's skin. Hence at trim:

Σ Moments at Confluence Point = 0



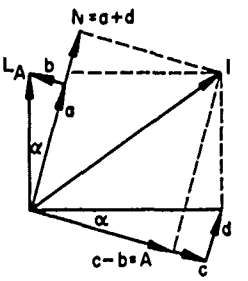
Positive Moments are Clockwise

(1) $0 = mW_N + nW_A - t\,L_n - uL_a - rN + sA + M$

Resolve Aero L_A & D into N and A by:

$$\cos \alpha = \frac{a}{L_A} \text{ and } \frac{c}{D}$$

$$\sin \alpha = \frac{b}{L_A} \text{ and } \frac{d}{D}$$



$$a = L_A \cos\alpha \qquad N = L_A \cos\alpha + D \sin\alpha$$
$$b = L_A \sin\alpha \qquad A = D \cos\alpha - L_A \sin\alpha$$
$$c = D \cos\alpha$$
$$d = D \sin\alpha$$

(2) $$0 = mW_N + nW_A - tL_n - uL_a - rL_A \cos\alpha - rD \sin\alpha + sD \cos\alpha - sL_A \sin\alpha + M$$

$$L_a = L_G \sin\alpha \qquad W_A = W \sin\alpha$$
$$L_n = L_G \cos\alpha \qquad W_N = W \cos\alpha$$

(3) $$0 = mW \cos\alpha + nW \sin\alpha - tL_G \cos\alpha - uL_G \sin\alpha - rL_A \cos\alpha - rD \sin\alpha + sD \cos\alpha - sL_A \sin\alpha + M$$

(4) $$0 = mW + nW \tan\alpha - tL_G - uL_G \tan\alpha - rL_A - rD \tan\alpha + sD - sL_A \tan\alpha + M/\cos\alpha$$

(5) $$0 = mW - tL_G + \tan\alpha\,(nW - uL_G) - rL_A - rD \tan\alpha + sD - sL_A \tan\alpha + M/\cos\alpha$$

Let $a = dC_L/d\alpha$, $C_{L_O} = 0$, then: $L_A = a\alpha q\, V_B^{2/3}$

$b = C_{D_O}$ and $c = dC_D/d\alpha^2$

then: $C_D = b + c\alpha^2$ and: $D = (b + c\alpha^2)\, q\, V_B^{2/3}$

(6) $$0 = mW - tL_G + \tan\alpha\,(nW - uL_G) - ra\,\alpha\, q\, V_B^{2/3} - r(b + c\alpha^2)\, q\, V_B^{2/3} \tan\alpha + s(b + c\alpha^2)\, q\, V_B^{2/3} - sa\,\alpha\, q\, V_B^{2/3} \tan\alpha + \frac{C_M\, q\, V_B^{2/3}\, \bar{c}}{\cos\alpha}$$

Let $K = q\, V_B^{2/3}$

(7) $$0 = mW - tL_G + \tan\alpha\,(nW - uL_G) - K\,[ra\,\alpha + r\,(b + c\alpha^2)\tan\alpha - s(b + c\alpha^2) + sa\,\alpha \tan\alpha] + \frac{C_M\, \bar{c}\, K}{\cos\alpha}$$

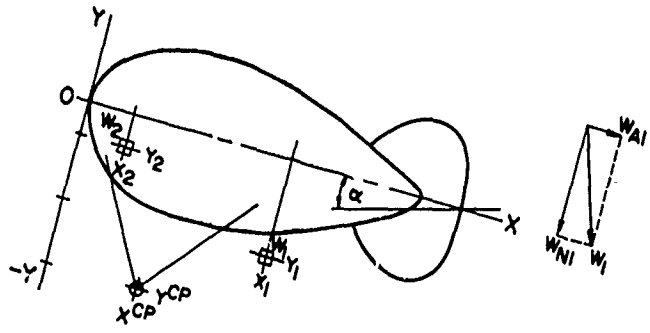
(8) $$0 = mW - tL_G + \tan\alpha\,(nW - uL_G) - K\,[ra\,\alpha - sb - sc\alpha^2 + \tan\alpha\,(sa\,\alpha + rb + rc\alpha^2)] + \frac{C_M\, \bar{c}\, K}{\cos\alpha}$$

To allow for adding extra loads (equipment, counter-weights, etc.) at any position on the balloon, consider the following two weights:

M_1, Moment about Conf Point $= W_{N1}(X_1 - X^{CP}) + W_{A1}(y_1 - y^{CP})$

$$M_1 = W_1 \cos\alpha\,(x_1 - x^{CP}) + W_1 \sin\alpha\,(y_1 - y^{CP})$$

$$M_2 = W_2 \cos\alpha\,(x_2 - x^{CP}) + W_2 \sin\alpha\,(y_2 - y^{CP})$$



$$\Sigma M \text{ extra} = M_1 + M_2$$

$$\frac{\Sigma M \text{ extra}}{\cos \alpha} = W_1 (x_1 - x^{CP}) + W_2 (x_2 - x^{CP}) + \tan \alpha [W_1 (y_1 - y^{CP}) + W_2 (y_2 - y^{CP})]$$

$$\frac{\Sigma M \text{ extra}}{\cos \alpha} = \Sigma W_e (x - x^{CP}) + \tan \alpha \, \Sigma W_e (y - y^{CP}) \tag{9}$$

Letting $L = L_G$ for clarity and adding the provision for extra weights, Eq. (8) expands to

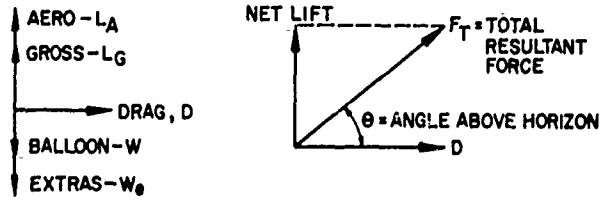
$$0 = mW - tL + \tan \alpha (nW - uL) \quad \text{(Mech. Mom.)}$$

$$- K[ra\,\alpha - sb - sc\alpha^2 + \tan \alpha (sa\,\alpha + rb + rc\alpha^2)] + \frac{C_M \bar{c} K}{\cos \alpha} \quad \text{(Aero Mom.)}$$

$$+ \cos \alpha [\Sigma W_e (x - x^{CP}) + \tan \alpha \, \Sigma W_e (y - y^{CP})] \quad \text{(Extras Mom.)} \tag{10}$$

B. After solving Eq. (10) for α_{trim}, the coefficients C_L, C_D, C_M, as well as L_A, D, M_o, can be calculated.

Then solution for the total force and its angle at the confluence point are known.



C. A 2 constant form for density ratio is utilized in this and other programs.

$$\frac{\ln \rho/\rho_o}{z} = a_o + a_1 z$$

where

$$a_1 = -1.7772^{-10}$$

$$a_o = -2.81361^{-5}$$

D. Dimensions m, n, r, s, t and u are calculated by program after user entries of

x^{CP} and y^{CP} - Confluence Point
x_{CG} and y_{CG} - Center Gravity
x_{CB} and Y_{CB} - Center of Buoyancy
x_{ARC} - Aero Ref. Center (y_{ARC} = o assumed)

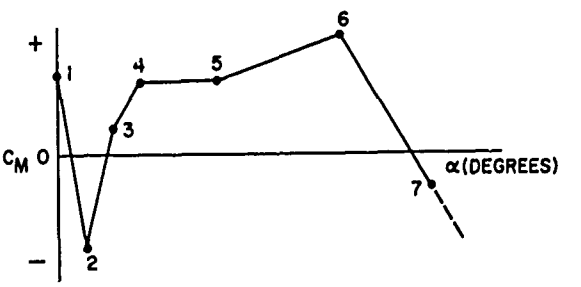
E. Aerocynamic coefficients in this general program are handled as inputs also. However, options at the end of program allow repeated passes without re-entry of these coefficients, balloon dimensions, or other parameters.

$\frac{dC_L}{d\alpha}$ = a in Moment Equation - Slope of the lift coefficient curve where $C_L = 0$ at $\alpha = 0$

C_{Do} = b in Moment Equation - Drag coefficient at $\alpha = 0$

$\frac{dC_D}{d\alpha^2}$ = c in Moment Equation - Second constant in drag coefficient form $C_D + \frac{dC_D}{d\alpha^2}\alpha^2$

Pitching Moment Coefficient, C_M, was found, with at least one balloon to have a variation with α that could be defined by a series of straight lines.

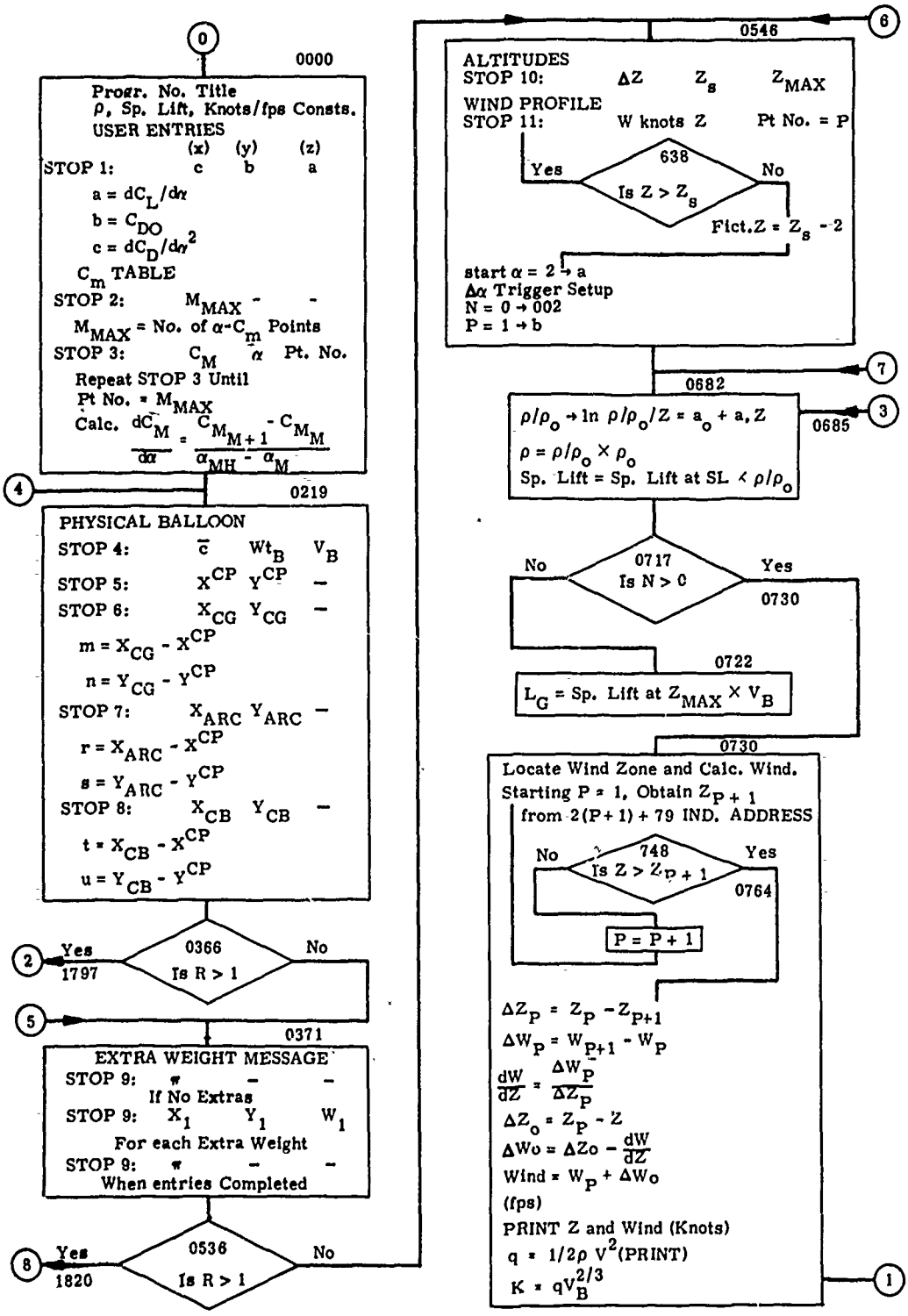


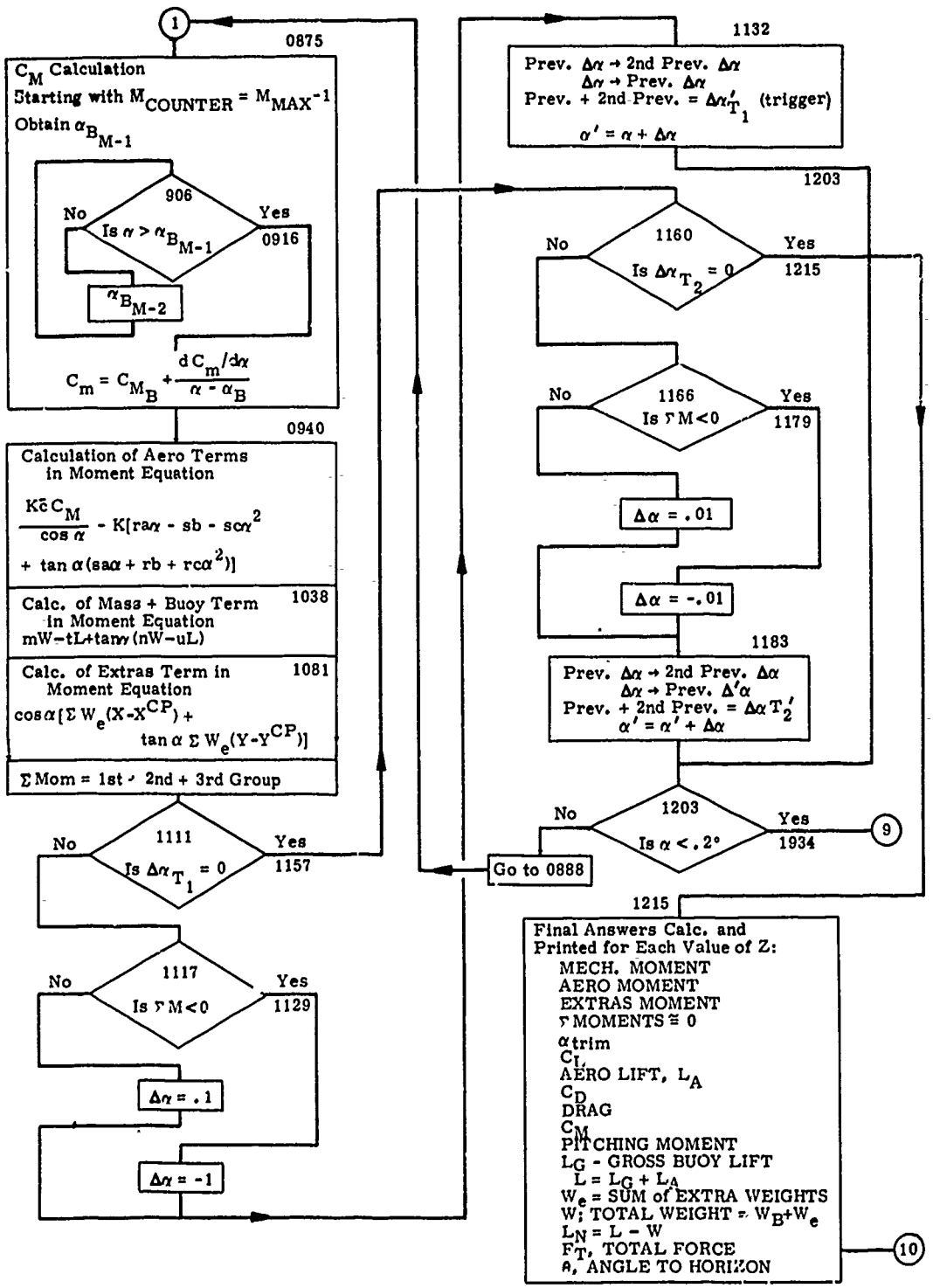
This requires entries (up to a maximum of 7 sets of entries) of significant points in the following manner which are stored and retrieved by use of region number codes. $dC_M/d\alpha$ values of each region are computed and stored at time of entry. Subscript B used here to indicate base value of a region, that is, the values at point number 1 are the base values for the region between points 1 and 2.

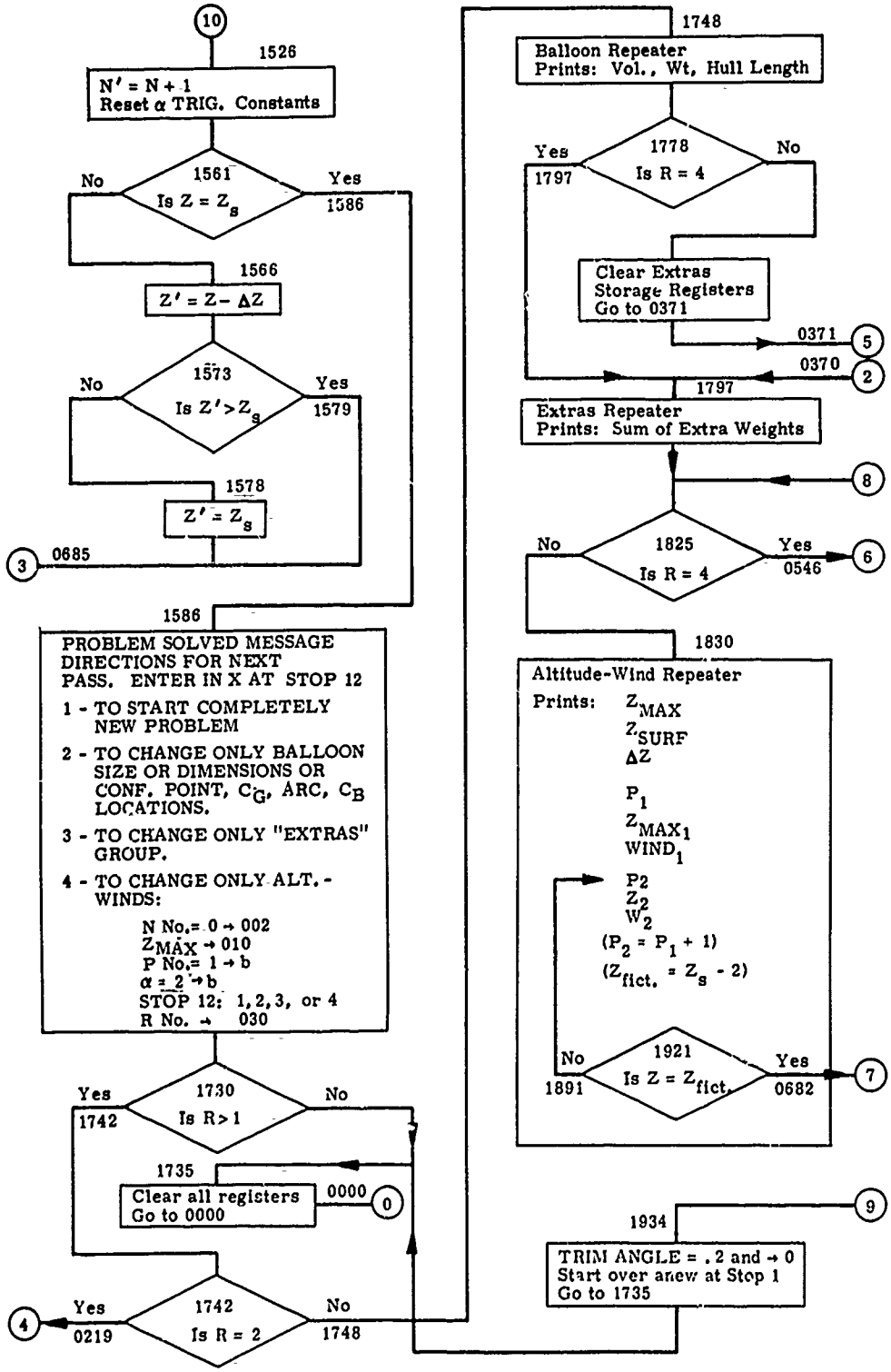
Register	(Z)	(Y)	(X)
	Point No.	α_B	C_{M_B}
Entry	1		
Entry	2		
Entry	3		
Entry	4		
Entry	5		
Entry	6		
Entry	7		

To calculate: $C_M = C_{M_B} + \frac{dC_M}{d\alpha} (\alpha - \alpha_B)$

3.3.3 FLOW CHART




1
0875
C_M Calculation
Starting with $M_{COUNTER} = M_{MAX}-1$
Obtain $\alpha_{B_{M-1}}$
906
No
Is $\alpha > \alpha_{B_{M-1}}$
Yes
0916
$\alpha_{B_{M-2}}$
$C_m = C_{M_B} + \frac{dC_m/d\alpha}{\alpha - \alpha_B}$
0940
Calculation of Aero Terms in Moment Equation
$\frac{K\bar{c}C_M}{\cos\alpha} - K[ra\alpha - sb - sc\alpha^2 + \tan\alpha(sa\alpha + rb + rc\alpha^2)]$
Calc. of Mass + Buoy Term in Moment Equation 1038
$mW - tL + tan\gamma(nW - uL)$
Calc. of Extras Term in Moment Equation 1081
$\cos\alpha[\Sigma W_e(X - X^{CP}) + \tan\alpha \Sigma W_e(Y - Y^{CP})]$
Σ Mom = 1st + 2nd + 3rd Group
1111
No
Is $\Delta\alpha_{T_1} = 0$
Yes
1157
1117
No
Is $\Sigma M < 0$
Yes
1129
$\Delta\alpha = .1$
$\Delta\alpha = -1$
1132
Prev. $\Delta\alpha \rightarrow$ 2nd Prev. $\Delta\alpha$
$\Delta\alpha \rightarrow$ Prev. $\Delta\alpha$
Prev. + 2nd Prev. = $\Delta\alpha'_{T_1}$ (trigger)
$\alpha' = \alpha + \Delta\alpha$
1203
1160
No
Is $\Delta\alpha_{T_2} = 0$
Yes
1215
1166
No
Is $\Sigma M < 0$
Yes
1179
$\Delta\alpha = .01$
$\Delta\alpha = -.01$
1183
Prev. $\Delta\alpha \rightarrow$ 2nd Prev. $\Delta\alpha$
$\Delta\alpha \rightarrow$ Prev. $\Delta'\alpha$
Prev. + 2nd Prev. = $\Delta\alpha T'_2$
$\alpha' = \alpha' + \Delta\alpha$
1203
No
Is $\alpha < .2°$
Yes
1934
9
Go to 0888
1215
Final Answers Calc. and Printed for Each Value of Z:
MECH. MOMENT
AERO MOMENT
EXTRAS MOMENT
Σ MOMENTS $\cong$ 0
α trim
C_L
AERO LIFT, L_A
C_D
DRAG
C_M
PITCHING MOMENT
L_G - GROSS BUOY LIFT
$L = L_G + L_A$
W_e = SUM of EXTRA WEIGHTS
W; TOTAL WEIGHT = $W_B + W_e$
$L_N = L - W$
F_T, TOTAL FORCE
θ, ANGLE TO HORIZON
10



Note: In flow chart, N is altitude point counter, P is wind profile point number and is repeater code for starting new problem.

3.3.4 OPERATING INSTRUCTIONS

KEY STROKES	ENTRIES (X)	ENTRIES (Y)	ENTRIES (Z)	PRINTS
RUN				
END				
FIX, 2, 3, ----				(No. of desired decimal places)
CONT	(X)	(Y)	(Z)	Program No. and Title
Stop 1-1-1, Enter:	$c = \frac{dC_D}{d\alpha^2}$	$b = C_{Do}$	$a = \frac{dC_L}{d\alpha}$	
CONT				a b c
Stop 2-2-2, Enter:	M = No. of C_M Pts	-	-	
CONT				C_M Table
Stop 3-3-, Enter:	C_M	α	Pt. No. (start #1)	
CONT				Pt. No. α C_M Repeats until all points entered at succ. Stops No. 3
Stop 4-4-4, Enter:	$\bar{c}$	W_B	V_B	
CONT				V_B, Balloon Volume CF W_B, Balloon Volume lb $\bar{c}$, Length, Hull, ft
Stop 5-5-5, Enter:	X^{CP}	Y^{CP}	-	
CONT				X^{CP}, Confl. Point X, ft Y^{CP}, Confl. Point Y, ft
Stop 6-6-6, Enter:	X_{CG}	Y_{CG}	-	
CONT				X_{CG}, Center of gravity X, ft Y_{CG}, Center of gravity Y, ft m, ft n, ft
Stop 7-7-7, Enter:	X_{ARC}	Y_{ARC}	-	
CONT				X_{ARC}, ft Y_{ARC}, ft r, ft s, ft

Stop 8-8-8, Enter:	X_{CB}	Y_{CB}	-	
CONT				X_{CB}, Center of Buoyancy X, ft Y_{CB}, Center of Buoyancy Y, ft t, ft u, ft Directions for "Extra" weights; Ent. ∏ in X if none. Ent. Wt. in Z, y in Y, x in X. Ent. ∏ in X when entries made complete
Stop 9-9-9, Enter:	∏	-	-	
	(If no Extras")			
Stop 9-9-9, Enter:	X_1	Y_1	W_1	
	(For each "extra" weight)			
Stop 9-9-9, Enter:	π			
	(After all weights entered)			
CONT				W_1 For each X_1 extra if Y_1 any are entered ALTITUDES
Stop 10-10-10, Enter:	ΔZ	Z_S	Z_{MAX}	
CONT				Z_{MAX} Z_{max}, ft MSL Z_S, ft, MSL ΔZ, ft WIND PROFILE
Stop 11-11-11, Enter:	Wind	Z	Pt. No. (Start No. 1)	
CONT				Pt, No. Z, Alt. Ft Wind, Knots 1st point must be Z max. Repeats for each point entered until last point must be Z_S.

Program now takes over and computes and prints following group of parameters starting at $Z = Z_{max}$, then at decreasing altitudes $Z = Z_M - \Delta Z$, $Z = Z_M - 2\Delta Z$, etc. to and including $Z = Z_S$. Values of parameters appear on tape on next line below the word.

ALT. ft
WIND, Knots
DYN. PRES. lb/ft^2
MECH. MOM., ft-lb
AERO MOM., ft-lb
EXTRAS MOM. ft-lb
SUM OF MOM., ft-lbs, (~ 0)
Trim Angle Atck.
C_L
AERO LIFT, L_A, lb
C_D
DRAG, D, lb
C_M
AERO P. MOM. (about the ARC)
GROSS BUOYANT LIFT, L_G, lb
TOTAL LIFT, $L = L_G + L_A$, lb
SUM "EXTRA" WTS, W_e, lb
TOT. WEIGHT, $W = W_B + W_e$, lb
NET LIFT, $L = L - W$, lb
TOTAL FORCE F_T, lb
ANGLE TO HORIZON, θ, deg

After $Z = Z_S$ condition is printed:

Prob. Solved
J.B.W. 76.003
Enter in X
1. To Start Anew
2. To Change Baln. Dim.
3. To Change Extras
4. To Change Alts and Wind Profile

Stop 1? Enter:	1, 2, 3, or 4		
CONT	-	-	
If Entry is:			
1	2	3	4
Goes to Start. Reprints Title. User Reenters. Complete Input.	PNTS: Physical Baln. Stops 4, 5, 6, 7, 8 repeated for reentry. Then auto pnts. Sum of extra wts, alts. max. surf, Δ, wind profile. Continues into computations.	PNTS: Vol, Wt, Length Hull extra wt message Stops 9 repeated for reentry then auto pnts alts, max, surf, Δ, wind profile. Continues into computations.	PNTS: Vol, Wt, Length hull, sum of extra wts, alts, max, surf, Δ, wind profile. Continues into computations.

3.3.5. SAMPLE INPUT DATA FORM

INPUT			76.002, 76.003, 76.004, and 76.005			
			76.003, 76.004, 76.005 EXTRA WEIGHT TABLE		76.003 and 76.005 WIND PROFILE*	
Balloon Volume	V_B	cu ft	W_1	lb	No. 1	1
Ballonet Volume	v	cu ft	Y_1	ft	Z_{ML} ML	
Balloon Weight	W_B	lb	X_1	ft	Wind, knots	
Hull Length	$\bar{c}$	ft	W_2		No. 2	2
① Location of Confluence Pt.	Y^{CP}	ft	Y_2		Z_2	
	X^{CP}	ft	X_2		$Wind_2$	
① Location of Center of Gravity	Y^{CG}	ft	W_3		No. 3	3
	X^{CG}	ft	Y_3		Z_3	
② Location of Center of Buoyancy	Y^{CB}	ft	X_3		$Wind_3$	
	X^{CB}	ft	W_4		No. 4	4
③ Location of Aero Reference Center	Y^{ARC}	ft	Y_4		Z_4	
	X^{ARC}	ft	X_4		$Wind_4$	
Altitude, Max	Z_M	ft	W_5		No. 5	5
Altitude, Surf	Z_S	ft	Y_5		Z_5	
Increment of Alt	ΔZ	ft	X_5		$Wind_5$	
④ $dC_L/d\alpha$	a		W_6		No. 6	6
⑤ C_{D_O}	b		Y_6		Z_6	
⑥ $dC_D/d\alpha^2$	c		X_6		$Wind_6$	
③ C_M TABLE*			W_7		No. 7	7
NO. 1	1		Y_7		Z_7	
α_1	0	deg	X_7		$Wind_7$	
C_{M1}			W_8		No. 8	8
NO. 2	2		Y_8		Z_8	
α_2		deg	X_8		$Wind_8$	
C_{M2}			W_9		No. 9	9
NO. 3	3		Y_9		Z_9	
α_3		deg	X_9		$Wind_9$	
C_{M3}			W_{10}		No. 10	10
NO. 4	4		Y_{10}		Z_{10}	
α_4		deg	X_{10}		$Wind_{10}$	
C_{M4}			W_{11}		No. 11	11
NO. 5	5		Y_{11}		Z_{11}	
α_5		deg	X_{11}		$Wind_{11}$	
C_{M5}			W_{12}		No. 12	12
NO. 6	6		Y_{12}		Z_{12}	
α_6		deg	X_{12}		$Wind_{12}$	
C_{M6}			W_{13}		No. 13	13
NO. 7	7		Y_{13}		Z_{13}	
α_7		deg	X_{13}		$Wind_{13}$	
C_{M7}						

① See Note 76.005
② Req'd for 76.002 and 76.003
③ Req 1 for 76.003 only
* A minimum of two points must be used, a maximum of seven points may be used. First point must be for $\alpha = 0°$

Any number of extra weights may be used. One entry can be Instrument Package and Payload. If these are at Confluence Point make
$Y = Y^{CP}$
$X = X^{CP}$

A minimum of 2 Points must be used and a maximum of 13 may be used. First must be Z_{MIN} and last must be Z_{MAX}. 76.004 requires one value of wind.

3.3.6 PROGRAM 76.003 - TRIM, GENERAL BALLOON

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0000	--CLR	0050	-- 8	0100	--XTO	0150	--RUP	0200	-- DN	0250	--PNT
0001	--FNT	0051	-- 1	0101	-- 5	0151	--PNT	0201	--DIV	0251	-- 2
0002	--FNT	0052	-- 3	0102	-- 5	0152	--PNT	0202	-- 2	0252	--RUP
0003	-- π	0053	-- 6	0103	--RUP	0153	--RUP	0203	--XTO	0253	--PNT
0004	-- a	0054	-- 1	0104	--PNT	0154	--XTO	0204	-- +	0254	-- 3
0005	-- 0	0055	--CHS	0105	--XTO	0155	-- 0	0205	-- 0	0255	--DIV
0006	-- G	0056	--EEX	0106	-- 5	0156	--YTO	0206	--YTO	0256	-- DN
0007	-- .	0057	-- 5	0107	-- 6	0157	--IND	0207	--IND	0257	--XEY
0008	--GTO	0058	--CHS	0108	--RUP	0158	-- 0	0208	-- 0	0258	-- H
0009	-- 7	0059	--XTO	0109	--XTO	0159	-- a	0209	-- b	0259	--XTO
0010	-- 6	0060	-- 0	0110	-- 5	0160	--RUP	0210	-- UP	0260	-- 0
0011	-- .	0061	-- 3	0111	-- 7	0161	--XTO	0211	--XFR	0261	-- 4
0012	-- 0	0062	-- 8	0112	--PNT	0162	-- -	0212	-- 2	0262	-- 1
0013	-- 0	0063	-- .	0113	--FNT	0163	-- 0	0213	-- 5	0263	-- 5
0014	-- 3	0064	-- 0	0114	--FNT	0164	--YTO	0214	--X>Y	0264	-- UP
0015	--CLR	0065	-- 6	0115	-- C	0165	--IND	0215	-- 0	0265	-- UP
0016	--XTO	0066	-- 5	0116	-- M	0166	-- 0	0216	-- 1	0266	--STP
0017	-- a	0067	-- 9	0117	--CNT	0167	--XEY	0217	-- 3	0267	--XTO
0018	-- I	0068	-- 9	0118	--XTO	0168	-- b	0218	-- 2	0268	-- 3
0019	-- N	0069	--XTO	0119	-- A	0169	--X=Y	0219	--FNT	0269	-- 6
0020	--CLX	0070	-- 0	0120	-- B	0170	-- 0	0220	--FNT	0270	--PNT
0021	-- G	0071	-- 3	0121	-- L	0171	-- 1	0221	-- π	0271	--YTO
0022	-- E	0072	-- 5	0122	-- E	0172	-- 3	0222	-- H	0272	-- 3
0023	-- H	0073	-- .	0123	--FNT	0173	-- 2	0223	--XFR	0273	-- 7
0024	-- .	0074	-- 0	0124	-- 2	0174	--XEY	0224	--YTO	0274	--XEY
0025	-- B	0075	-- 0	0125	-- UP	0175	-- -	0225	-- I	0275	--PNT
0026	-- A	0076	-- 2	0126	-- UP	0176	-- 3	0226	-- C	0276	--PNT
0027	-- L	0077	-- 3	0127	--STP	0177	-- X	0227	-- A	0277	-- 6
0028	-- L	0078	-- 7	0128	--XTO	0178	-- 5	0228	-- L	0278	-- UP
0029	-- 0	0079	-- 8	0129	-- 0	0179	-- 8	0229	--CNT	0279	-- UP
0030	-- 0	0080	--XTO	0130	-- 2	0180	-- +	0230	-- B	0280	--STP
0031	-- N	0081	-- 0	0131	-- 5	0181	--YTO	0231	-- A	0281	--PNT
0032	--FNT	0082	-- 3	0132	-- 3	0182	-- 0	0232	-- L	0282	--XEY
0033	-- 1	0083	-- 4	0133	-- UP	0183	--XFR	0233	-- N	0283	--PNT
0034	-- .	0084	-- 1	0134	-- UP	0184	--IND	0234	-- .	0284	-- UP
0035	-- 7	0085	-- .	0135	--STP	0185	-- 0	0235	--FNT	0285	--XFR
0036	-- 7	0086	-- 6	0136	--RUP	0186	--RUP	0236	-- 4	0286	-- 3
0037	-- 7	0087	-- 8	0137	--PNT	0187	--XEY	0237	-- UP	0287	-- 6
0038	-- 2	0088	-- 7	0138	--RUP	0188	-- -	0238	-- UP	0288	--RUP
0039	--CHS	0089	-- 8	0139	--YTO	0189	-- 1	0239	--STP	0289	--XEY
0040	--EEX	0090	--XTO	0140	-- b	0190	--XTO	0240	--YTO	0290	-- -
0041	-- 1	0091	-- 0	0141	--XTO	0191	-- -	0241	-- 1	0291	--XFR
0042	-- 0	0092	-- 3	0142	-- a	0192	-- 0	0242	--XTO	0292	-- 3
0043	--CHS	0093	-- 2	0143	--PNT	0193	--XFR	0243	-- 9	0293	-- 7
0044	--XTO	0094	-- 1	0144	-- 9	0194	--IND	0244	--RUP	0294	--XEY
0045	-- 0	0095	-- UP	0145	-- X	0195	-- 0	0245	--PNT	0295	--XTO
0046	-- 3	0096	-- UP	0146	-- 5	0196	-- UP	0246	--XTO	0296	-- 3
0047	-- 9	0097	--STP	0147	-- 8	0197	-- a	0247	-- 4	0297	--PNT
0048	-- 2	0098	--RUP	0148	-- +	0198	--XEY	0248	-- 2	0298	-- DN
0049	-- .	0099	--PNT	0149	-- 1	0199	-- -	0249	--RUP	0299	-- -

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0300	--YTO	0350	-- 3	0400	-- N	0450	--IND	0500	--PNT	0550	--XTO
0301	-- 4	0351	-- 7	0401	-- E	0451	--XTO	0501	--XEY	0551	--YTO
0302	-- DN	0352	--XEY	0402	--CLR	0452	--YTO	0502	-- -	0552	-- .
0303	--PNT	0353	--PNT	0403	-- E	0453	-- .	0503	--XFR	0553	--FNT
0304	--PNT	0354	-- DN	0404	-- N	0454	-- E	0504	-- 3	0554	-- 1
0305	-- 7	0355	-- -	0405	--XTO	0455	-- N	0505	-- 1	0555	-- 0
0306	-- UP	0356	--YTO	0406	-- .	0456	--XTO	0506	-- X	0556	-- UP
0307	-- UP	0357	-- 8	0407	--IND	0457	-- E	0507	--YTO	0557	-- UP
0308	--STP	0358	-- DN	0408	--XTO	0458	-- α	0508	-- +	0558	--STP
0309	--PNT	0359	--PNT	0409	-- .	0459	-- E	0509	-- 5	0559	--RUP
0310	--XEY	0360	--PNT	0410	-- I	0460	-- D	0510	-- 2	0560	--PNT
0311	--FNT	0361	--XFR	0411	-- N	0461	--FMT	0511	--RUP	0561	--XTO
0312	-- UP	0362	-- 3	0412	--CNT	0462	-- 9	0512	-- X	0562	-- 1
0313	--XFR	0363	-- 0	0413	--XSQ	0463	-- UP	0513	--YTO	0563	-- 0
0314	-- 3	0364	-- UP	0414	--CLR	0464	-- UP	0514	-- +	0564	--XTO
0315	-- 6	0365	-- 1	0415	--XFR	0465	--STP	0515	-- 0	0565	-- 2
0316	--RUP	0366	--X<Y	0416	--CNT	0466	--YTO	0516	-- 5	0566	-- 9
0317	--XEY	0367	-- 1	0417	-- I	0467	-- 3	0517	-- 1	0567	--YTO
0318	-- -	0368	-- 7	0418	-- N	0468	-- 1	0518	-- 9	0568	-- 1
0319	--XFR	0369	-- 9	0419	--CNT	0469	--XEY	0519	-- UP	0569	-- 2
0320	-- 3	0370	-- 7	0420	--XFR	0470	-- π	0520	-- UP	0570	--RUP
0321	-- 7	0371	--FMT	0421	--CLX	0471	--X=Y	0521	--STP	0571	--PNT
0322	--XEY	0372	--FMT	0422	--CNT	0472	-- 0	0522	--YTO	0572	--XTO
0323	--PNT	0373	-- E	0423	-- YE	0473	-- 5	0523	-- 3	0573	-- 1
0324	--XTO	0374	-- YE	0424	--CNT	0474	-- 3	0524	-- 1	0574	-- 1
0325	-- 5	0375	--XTO	0425	-- I	0475	-- 6	0525	--XEY	0575	--RUP
0326	-- DN	0376	-- α	0426	-- N	0476	--XFR	0526	-- π	0576	--PNT
0327	-- -	0377	-- A	0427	--CNT	0477	-- 3	0527	--X=Y	0577	--FNT
0328	--YTO	0378	--CNT	0428	-- YE	0478	-- 1	0528	-- 0	0578	--FNT
0329	-- 6	0379	--IND	0429	--CLR	0479	--RUP	0529	-- 5	0579	--IND
0330	-- DN	0380	--XTO	0430	-- E	0480	--PNT	0530	-- 3	0580	-- I
0331	--PNT	0381	--YTO	0431	-- N	0481	--XTO	0531	-- 6	0581	-- N
0332	--PNT	0382	-- .	0432	--XTO	0482	-- +	0532	--GTO	0582	-- D
0333	-- 8	0383	--CLR	0433	-- .	0483	-- 5	0533	-- 4	0583	--CNT
0334	-- UP	0384	-- E	0434	--CHS	0484	-- 0	0534	-- 7	0584	-- π
0335	-- UP	0385	-- N	0435	--CNT	0485	--XTO	0535	-- 6	0585	-- α
0336	--STP	0386	--XTO	0436	-- I	0486	-- 3	0536	--XFR	0586	-- 0
0337	--PNT	0387	-- .	0437	-- N	0487	-- 1	0537	-- 3	0587	-- F
0338	--XEY	0388	--CHS	0438	--CNT	0488	--XFR	0538	-- 0	0588	-- I
0339	--PNT	0389	--CNT	0439	-- YE	0489	-- 3	0539	-- UP	0589	-- L
0340	-- UP	0390	-- I	0440	--CNT	0490	-- 6	0540	-- 1	0590	-- E
0341	--XFR	0391	-- N	0441	-- A	0491	--RUP	0541	--X<Y	0591	--FNT
0342	-- 3	0392	--CNT	0442	-- F	0492	--PNT	0542	-- 1	0592	-- 1
0343	-- 6	0393	-- YE	0443	--XTO	0493	--XEY	0543	-- 8	0593	-- 1
0344	--RUP	0394	--CNT	0444	-- E	0494	-- -	0544	-- 2	0594	-- UP
0345	--XEY	0395	-- I	0445	-- α	0495	--XFR	0545	-- 0	0595	-- UP
0346	-- -	0396	-- F	0446	-- A	0496	-- 3	0546	--FMT	0596	--STP
0347	--YTO	0397	--CLR	0447	-- L	0497	-- 7	0547	--FMT	0597	--RUP
0348	-- 7	0398	-- N	0448	-- L	0498	--RUP	0548	-- A	0598	--PNT
0349	--XFR	0399	-- 0	0449	--CNT	0499	--PNT	0549	-- L	0599	--RUP

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0600	--PMT	0650	-- 0	0700	-- UP	0750	-- 7	0800	--XFR	0850	--IND
0601	--RUP	0651	--XTO	0701	--XFR	0751	-- 6	0801	-- 1	0851	-- I
0602	--YTO	0652	-- α	0702	-- 3	0752	-- 4	0802	-- 0	0852	-- N
0603	-- 3	0653	-- 1	0703	-- 4	0753	-- 1	0803	-- -	0853	-- D
0604	-- 1	0654	-- 1	0704	-- X	0754	-- UP	0804	-- DN	0854	--FMT
0605	--PMT	0655	--XTO	0705	--YTO	0755	-- 6	0805	-- X	0855	--PMT
0606	--PMT	0656	-- 4	0706	-- 1	0756	-- +	0806	-- 2	0856	--XFR
0607	--XEY	0657	-- 3	0707	-- 3	0757	--YTO	0807	--XTO	0857	-- 1
0608	-- 2	0658	--XTO	0708	-- DN	0758	-- 6	0808	-- -	0858	-- 5
0609	--RUP	0659	-- 4	0709	--XFR	0759	--GTO	0809	-- 0	0859	--XSQ
0610	-- X	0660	-- 5	0710	-- 3	0760	-- 0	0810	--XFR	0860	-- UP
0611	-- 8	0661	--XTO	0711	-- 5	0761	-- 7	0811	--IND	0861	--XFR
0612	-- 0	0662	-- 4	0712	-- X	0762	-- 3	0812	-- 0	0862	-- 1
0613	-- +	0663	-- 6	0713	--XFR	0763	-- 0	0813	-- +	0863	-- 3
0614	--YTO	0664	--XTO	0714	-- 2	0764	-- 2	0814	--XFR	0864	-- X
0615	-- 0	0665	-- 0	0715	-- UP	0765	--XTO	0815	-- 3	0865	-- 2
0616	--XFR	0666	-- 4	0716	-- 0	0766	-- -	0816	-- 2	0866	--DIV
0617	-- 3	0667	-- 8	0717	--X<Y	0767	-- 0	0817	--YTO	0867	--XFR
0618	-- 2	0668	-- 0	0718	-- 0	0768	--XFR	0818	-- 1	0868	-- 4
0619	--RUP	0669	--XTO	0719	-- 7	0769	--IND	0819	-- 5	0869	-- 1
0620	-- X	0670	-- 4	0720	-- 3	0770	-- 0	0820	--DIV	0870	--XEY
0621	-- 1	0671	-- 4	0721	-- 0	0771	--XTO	0821	--XFR	0871	-- X
0622	--YTO	0672	--XTO	0722	--XFR	0772	-- 5	0822	-- 1	0872	--YTO
0623	--IND	0673	-- 4	0723	-- 4	0773	-- 8	0823	-- 0	0873	-- 1
0624	-- 0	0674	-- 7	0724	-- 2	0774	--XEY	0824	--FMT	0874	-- 6
0625	--XTO	0675	--XTO	0725	--RUP	0775	-- -	0825	--FMT	0875	--FMT
0626	-- -	0676	-- 0	0726	-- X	0776	-- 1	0826	-- A	0876	--FMT
0627	-- 0	0677	-- 0	0727	--YTO	0777	--XTO	0827	-- L	0877	-- D
0628	--XFR	0678	-- 2	0728	-- 1	0778	-- +	0828	--XTO	0878	--XFR
0629	-- 3	0679	-- 1	0729	-- 4	0779	-- 0	0829	--FMT	0879	-- N
0630	-- 1	0680	--XTO	0730	-- 6	0780	--XFR	0830	--PMT	0880	-- .
0631	--XTO	0681	-- 6	0731	-- UP	0781	--IND	0831	-- UP	0881	-- π
0632	--IND	0682	--XFR	0732	-- 1	0782	-- 0	0832	--XFR	0882	-- α
0633	-- 0	0683	-- 1	0733	-- +	0783	-- UP	0833	-- 1	0883	-- E
0634	-- UP	0684	-- 0	0734	-- 2	0784	-- 2	0834	-- 1	0884	--YTO
0635	--XFR	0685	-- UP	0735	-- X	0785	--XTO	0835	-- -	0885	-- .
0636	-- 1	0686	-- UP	0736	-- 7	0786	-- +	0836	-- DN	0886	--FMT
0637	-- 1	0687	--XFR	0737	-- 9	0787	-- 0	0837	--FMT	0887	--PMT
0638	--X<Y	0688	-- 3	0738	-- +	0788	--XFR	0838	--FMT	0888	--XFR
0639	-- 0	0689	-- 9	0739	--YTO	0789	--IND	0839	-- H	0889	-- 2
0640	-- 5	0690	-- X	0740	-- 0	0790	-- 0	0840	-- E	0890	-- 5
0641	-- 9	0691	--XFR	0741	--XFR	0791	--XEY	0841	-- 1	0891	-- UP
0642	-- 2	0692	-- 3	0742	--IND	0792	-- -	0842	-- G	0892	-- 1
0643	-- 2	0693	-- 8	0743	-- 0	0793	-- DN	0843	-- H	0893	-- -
0644	--XTO	0694	-- +	0744	-- UP	0794	--XEY	0844	--XTO	0894	-- 3
0645	-- +	0695	-- DN	0745	--XFR	0795	--DIV	0845	--FMT	0895	-- X
0646	-- 0	0696	-- X	0746	-- 1	0796	--XFR	0846	--PMT	0896	-- 5
0647	-- -	0697	-- DN	0747	-- 0	0797	-- 5	0847	-- DN	0897	-- 7
0648	--YTO	0698	-- J	0748	--X<Y	0798	-- 8	0848	--FMT	0898	-- +
0649	--IND	0699	-- UP	0749	-- 0	0799	-- UP	0849	--FMT	0899	--YTO

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0900	0	0950	YTO	1000	XFR	1050	X	1100	0	1150	YTO
0901	XFR	0951	1	1001	5	1051	DN	1101	+	1151	α
0902	IND	0952	8	1002	6	1052	-	1102	XFR	1152	GTO
0903	0	0953	α	1003	X	1053	YTO	1103	1	1153	1
0904	UP	0954	UP	1004	DN	1054	3	1104	9	1154	2
0905	α	0955	XSQ	1005	+	1055	1	1105	+	1155	0
0906	X>Y	0956	UP	1006	α	1056	XFR	1106	0	1156	3
0907	0	0957	XFR	1007	UP	1057	1	1107	UP	1157	XFR
0908	9	0958	6	1008	XFR	1058	UP	1108	XFR	1158	4
0909	1	0959	X	1009	6	1059	XFR	1109	4	1159	6
0910	9	0960	XFR	1010	X	1060	4	1110	3	1160	X=Y
0911	3	0961	5	1011	XFR	1061	X	1111	X=Y	1161	1
0912	XTO	0962	7	1012	5	1062	XFR	1112	1	1162	2
0913	-	0963	X	1013	5	1063	1	1113	1	1163	1
0914	0	0964	XFR	1014	X	1064	4	1114	5	1164	5
0915	GTO	0965	5	1015	DN	1065	UP	1115	7	1165	DN
0916	9	0966	5	1016	XEY	1066	XFR	1116	DN	1166	X>Y
0917	0	0967	RUP	1017	+	1067	8	1117	X>Y	1167	1
0918	1	0968	X	1018	α	1068	X	1118	1	1168	1
0919	XEY	0969	XFR	1019	0	1069	DN	1119	1	1169	7
0920	-	0970	5	1020	X	1070	-	1120	2	1170	9
0921	2	0971	X	1021	XFR	1071	α	1121	9	1171	.
0922	XTO	0972	XFR	1022	3	1072	0	1122	.	1172	0
0923	+	0973	5	1023	1	1073	X	1123	1	1173	1
0924	0	0974	6	1024	XEY	1074	XFR	1124	GTO	1174	GTO
0925	XFR	0975	RUP	1025	+	1075	3	1125	1	1175	1
0926	IND	0976	RUP	1026	XFR	1076	1	1126	1	1176	1
0927	0	0977	XEY	1027	1	1077	+	1127	3	1177	8
0928	X	0978	-	1028	6	1078	YTO	1128	2	1178	3
0929	1	0979	XFR	1029	X	1079	2	1129	.	1179	.
0930	XTO	0980	6	1030	XFR	1080	0	1130	1	1180	0
0931	-	0981	RUP	1031	1	1081	XFR	1131	CHS	1181	1
0932	0	0982	X	1032	8	1082	5	1132	UP	1182	CHS
0933	XFR	0983	DN	1033	XEY	1083	2	1133	XFR	1183	UP
0934	IND	0984	-	1034	-	1084	UP	1134	4	1184	XFR
0935	0	0985	YTO	1035	YTO	1085	α	1135	4	1185	4
0936	+	0986	3	1036	1	1086	0	1136	XTO	1186	7
0937	YTO	0987	1	1037	9	1087	X	1137	4	1187	XTO
0938	1	0988	α	1038	XFR	1088	XFR	1138	5	1188	4
0939	7	0989	UP	1039	1	1089	5	1139	YTO	1189	8
0940	XFR	0990	XSQ	1040	UP	1090	1	1140	4	1190	YTO
0941	9	0991	UP	1041	XFR	1091	+	1141	4	1191	4
0942	X	0992	XFR	1042	3	1092	α	1142	XEY	1192	7
0943	XFR	0993	5	1043	X	1093	N	1143	+	1193	XEY
0944	1	0994	7	1044	XFR	1094	X	1144	YTO	1194	÷
0945	6	0995	X	1045	1	1095	YTO	1145	4	1195	YTO
0946	X	0996	XFR	1046	4	1096	2	1146	3	1196	4
0947	α	0997	5	1047	UP	1097	1	1147	XEY	1197	6
0948	N	0998	X	1048	XFR	1098	XFR	1148	α	1198	XEY
0949	DIV	0999	RUP	1049	7	1099	2	1149	+	1199	α

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1200	+	1250	2	1300	FMT	1350	D	1400	0	1450	FMT
1201	YTO	1251	1	1301	C	1352	FMT	1401	YTO	1451	FMT
1202	α	1252	+	1302	L	1352	FMT	1402	YTO	1452	+
1203	.	1253	FMT	1303	FMT	1353	DN	1403	CNT	1453	DN
1204	2	1254	FMT	1304	UP	1354	FMT	1404	L	1454	FMT
1205	X>Y	1255	E	1305	XSQ	1355	FMT	1405	I	1455	FMT
1206	1	1256	YE	1306	XEY	1356	D	1406	F	1456	XTO
1207	9	1257	XTO	1307	UP	1357	α	1407	XTO	1457	0
1208	3	1258	α	1308	XFR	1358	A	1408	FMT	1458	XTO
1209	4	1259	A	1309	5	1359	G	1409	PNT	1459	.
1210	PSE	1260	YTO	1310	5	1360	FMT	1410	UP	1460	IND
1211	GTO	1261	CNT	1311	X	1361	PNT	1411	XFR	1461	E
1212	8	1262	M	1312	DN	1362	XTO	1412	2	1462	I
1213	8	1263	0	1313	PNT	1363	2	1413	2	1463	G
1214	8	1264	M	1314	UP	1364	3	1414	+	1464	H
1215	FMT	1265	.	1315	XFR	1365	XFR	1415	DN	1465	XTO
1216	FMT	1266	FMT	1316	1	1366	9	1416	FMT	1466	FMT
1217	M	1267	PNT	1317	6	1367	X	1417	FMT	1467	PNT
1218	E	1268	DN	1318	X	1368	XFR	1418	XTO	1468	-
1219	C	1269	FMT	1319	XEY	1369	1	1419	0	1469	XFR
1220	H	1270	FMT	1320	FMT	1370	7	1420	XTO	1470	2
1221	.	1271	YTO	1321	FMT	1371	X	1421	.	1471	3
1222	M	1272	1/X	1322	A	1372	FMT	1422	L	1472	XEY
1223	0	1273	M	1323	E	1373	FMT	1423	I	1473	FMT
1224	M	1274	CNT	1324	α	1374	C	1424	F	1474	FMT
1225	.	1275	0	1325	0	1375	M	1425	XTO	1475	M
1226	FMT	1276	F	1326	CNT	1376	FMT	1426	FMT	1476	E
1227	XFR	1277	CNT	1327	L	1377	PNT	1427	FMT	1477	XTO
1228	2	1278	M	1328	I	1378	DN	1428	UP	1478	CNT
1229	0	1279	0	1329	F	1379	FMT	1429	XFR	1479	L
1230	PNT	1280	M	1330	XTO	1380	FMT	1430	1	1480	I
1231	UP	1281	.	1331	FMT	1381	A	1431	UP	1481	F
1232	XFR	1282	FMT	1332	PNT	1382	E	1432	XFR	1482	XTO
1233	1	1283	PNT	1333	XTO	1383	α	1433	5	1483	FMT
1234	9	1284	α	1334	2	1384	0	1434	0	1484	PNT
1235	+	1285	FMT	1335	2	1385	CNT	1435	FMT	1485	XEY
1236	FMT	1286	FMT	1336	XFR	1386	π	1436	FMT	1486	A
1237	FMT	1287	XTO	1337	5	1387	.	1437	YTO	1487	FMT
1238	A	1288	α	1338	7	1388	M	1438	1/X	1488	FMT
1239	E	1289	I	1339	RUP	1389	0	1439	M	1489	XTO
1240	α	1290	M	1340	X	1390	M	1440	X>Y	1490	0
1241	0	1291	CNT	1341	XFR	1391	FMT	1441	E	1491	XTO
1242	CNT	1292	A	1342	5	1392	PNT	1442	YE	1492	A
1243	M	1293	M	1343	6	1393	XFR	1443	XTO	1493	L
1244	0	1294	G	1344	+	1394	1	1444	α	1494	CNT
1245	M	1295	L	1345	DN	1395	4	1445	A	1495	F
1246	.	1296	E	1346	X	1396	FMT	1446	X>Y	1496	0
1247	FMT	1297	FMT	1347	FMT	1397	FMT	1447	IND	1497	α
1248	PNT	1298	PNT	1348	FMT	1398	G	1448	XTO	1498	C
1249	XFR	1299	FMT	1349	C	1399	α	1449	YTO	1499	E

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1500	--FNT	1550	-- 4	1600	-- J	1650	-- N	1700	-- D	1750	--INT
1501	--FNT	1551	--XTO	1601	-- .	1651	-- C	1701	--YTO	1751	-- 0
1502	--KEY	1552	-- 4	1602	-- B	1652	-- E	1702	--FNT	1752	-- L
1503	--FNT	1553	-- 7	1603	-- .	1653	--CNT	1703	-- 0	1753	--CLX
1504	--FNT	1554	--XFR	.1604	--IND	1654	-- B	1704	--XTO	1754	--IND
1505	-- A	1555	-- 1	1605	-- .	1655	-- A	1705	-- 2	1755	--XTO
1506	-- N	1556	-- 0	1606	--CNT	1656	-- L	1706	--XFR	1756	--CLX
1507	-- G	1557	-- UP	1607	--CNT	1657	-- N	1707	-- 2	1757	-- L
1508	-- L	1558	--XFR	1608	-- 7	1658	-- D	1708	-- 9	1758	-- N
1509	-- E	1559	-- 1	1609	-- 6	1659	-- I	1709	--XTO	1759	-- G
1510	--CNT	1560	-- 1	1610	-- .	1660	-- M	1710	-- 0	1760	--XTO
1511	--XTO	1561	--X=Y	1611	-- 0	1661	-- .	1711	-- 1	1761	-- .
1512	-- 0	1562	-- 1	1612	-- 0	1662	--CLR	1712	-- 0	1762	-- H
1513	--CNT	1563	-- 5	1613	-- 3	1663	-- 3	1713	-- 1	1763	--1/X
1514	-- H	1564	-- 8	1614	--CLR	1664	--CNT	1714	--XTO	1764	-- L
1515	-- 0	1565	-- 6	1615	--CLR	1665	--XTO	1715	-- 6	1765	-- L
1516	--α	1566	--KEY	1616	--CLR	1666	-- 0	1716	-- 2	1766	--FNT
1517	-- I	1567	-- UP	1617	-- E	1667	--CNT	1717	--XTO	1767	--XFR
1518	--XSQ	1568	--XFR	1618	-- N	1668	-- C	1718	-- α	1768	-- 4
1519	-- 0	1569	-- 1	1619	--XTO	1669	-- H	1719	-- 1	1769	-- 2
1520	-- N	1570	-- 2	1620	-- .	1670	-- S	1720	-- 2	1770	--PNT
1521	--FNT	1571	-- -	1621	-- I	1671	-- .	1721	-- UP	1771	--XFR
1522	--PNT	1572	-- DN	1622	-- N	1672	-- E	1722	-- UP	1772	-- 1
1523	--PNT	1573	--X>Y	1623	--CNT	1673	-- YE	1723	--STP	1773	--PNT
1524	--PNT	1574	-- 1	1624	-- YE	1674	--XTO	1724	--PNT	1774	--XFR
1525	--PNT	1575	-- 5	1625	--CLR	1675	-- α	1725	-- UP	1775	-- 9
1526	-- 1	1576	-- 7	1626	-- 1	1676	-- A	1726	-- 1	1776	--PNT
1527	--XTO	1577	-- 9	1627	--CNT	1677	--YTO	1727	--YTO	1777	-- 4
1528	-- +	1578	-- DN	1628	--XTO	1678	--CLR	1728	-- 3	1778	--X=Y
1529	-- 0	1579	--XTO	1629	-- 0	1679	-- 4	1729	-- 0	1779	-- 1
1530	-- 0	1580	-- 1	1630	--CNT	1680	--CNT	1730	--X<Y	1780	-- 7
1531	-- 2	1581	-- 0	1631	--YTO	1681	--XTO	1731	-- 1	1781	-- 9
1532	-- 1	1582	--GTO	1632	--XTO	1682	-- 0	1732	-- 7	1782	-- 7
1533	-- 1	1583	-- 6	1633	-- A	1683	--CNT	1733	-- 4	1783	-- 0
1534	--XTO	1584	-- 8	1634	-- α	1684	-- C	1734	-- 2	1784	--XTO
1535	-- 4	1585	-- 5	1635	--XTO	1685	-- H	1735	-- K	1785	-- 5
1536	-- 3	1586	--FNT	1636	--CNT	1686	-- G	1736	--CLX	1786	-- 0
1537	--XTO	1587	--FNT	1637	-- A	1687	-- .	1737	--GTO	1787	--XTO
1538	-- 4	1588	-- π	1638	-- N	1688	-- A	1738	-- 0	1788	-- 5
1539	-- 5	1589	-- α	1639	-- E	1689	-- L	1739	-- 0	1789	-- 1
1540	--XTO	1590	-- 0	1640	--IND	1690	--XTO	1740	-- 0	1790	--XTO
1541	-- 4	1591	-- B	1641	--CLR	1691	--YTO	1741	-- 0	1791	-- 5
1542	-- 6	1592	-- .	1642	-- 2	1692	-- .	1742	-- 2	1792	-- 3
1543	--XTO	1593	--YTO	1643	--CNT	1693	--CLR	1743	--X=Y	1793	--GTO
1544	-- 0	1594	-- 0	1644	--XTO	1694	-- 0	1744	-- 0	1794	-- 3
1545	-- 4	1595	-- L	1645	-- 0	1695	-- α	1745	-- 2	1795	-- 7
1546	-- 8	1596	--INT	1646	--CNT	1696	--CNT	1746	-- 1	1796	-- 1
1547	-- 0	1597	-- E	1647	-- C	1697	--IND	1747	-- 9	1797	--FNT
1548	--XTO	1598	-- D	1648	-- H	1698	-- I	1748	--FNT	1798	--FNT
1549	-- 4	1599	--CLR	1649	-- A	1699	-- N	1749	--FNT	1799	--YTO

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1800	1/X	1850	L	1900	XFR	1950	CLR	2000	5		
1801	M	1851	XTO	1901	3	1951	A	2001	END		
1802	CNT	1852	A	1902	2	1952	N				
1803	0	1853	FNT	1903	DIV	1953	D				
1804	F	1854	XFR	1904	DN	1954	CNT				
1805	CNT	1855	1	1905	PNT	1955	EEX				
1806	E	1856	0	1906	PNT	1956	0				
1807	YE	1857	PNT	1907	1 .	1957	CNT				
1808	XTO	1858	XFR	1908	+	1958	CNT				
1809	α	1859	1	1909	XTO	1959	CLX				
1810	A	1860	1	1910	+	1960	YTO				
1811	CNT	1861	PNT	1911	0	1961	0				
1812	IND	1862	XFR	1912	XFR	1962	α				
1813	XTO	1863	1	1913	1	1963	α				
1814	YTO	1864	2	1914	1	1964	XFR				
1815	FNT	1865	PNT	1915	UP	1965	CLR				
1816	XFR	1866	FNT	1916	2	1966	XFR				
1817	5	1867	FNT	1917	-	1967	0				
1818	0	1868	IND	1918	XFR	1968	1/X				
1819	PNT	1869	I	1919	IND	1969	CNT				
1820	XFR	1870	N	1920	0	1970	M				
1821	3	1871	D	1921	X=Y	1971	1/X				
1822	0	1872	CNT	1922	0	1972	YTO				
1823	UP	1873	π	1923	6	1973	XTO				
1824	4	1874	α	1924	8	1974	CNT				
1825	X=Y	1875	0	1925	2	1975	YTO				
1826	0	1876	F	1926	RUP	1976	XTO				
1827	5	1877	I	1927	PNT	1977	A				
1828	4	1878	L	1928	XEY	1978	α				
1829	6	1879	E	1929	GTO	1979	XTO				
1830	FNT	1880	FNT	1930	1	1980	CLR				
1831	FNT	1881	1	1931	8	1981	A				
1832	A	1882	PNT	1932	9	1982	N				
1833	L	1883	UP	1933	1	1983	E				
1834	XTO	1884	8	1934	FNT	1984	IND				
1835	YTO	1885	1	1935	FNT	1985	CNT				
1836	.	1886	XTO	1936	XTO	1986	A				
1837	CLX	1887	0	1937	α	1987	XTO				
1838	M	1888	XFR	1938	I	1988	CNT				
1839	A	1889	IND	1939	M	1989	YTO				
1840	YE	1890	0	1940	CNT	1990	XTO				
1841	CLX	1891	PNT	1941	A	1991	0				
1842	YTO	1892	1	1942	N	1992	π				
1843	1/X	1893	XTO	1943	G	1993	CNT				
1844	α	1894	+	1944	L	1994	1				
1845	F	1895	0	1945	E	1995	FNT				
1846	CLX	1896	XFR	1946	CNT	1996	GTO				
1847	CLR	1897	IND	1947	SFL	1997	1				
1848	D	1898	0	1948	.	1998	7				
1849	E	1899	UP	1949	2	1999	3				

STORAGE REGISTERS

STORAGE	
b	Temp/P Count
a	α
000	IND. Use
001	Wt_B
002	N Count
003	m
004	n
005	r
006	s
007	t
008	w
009	$\bar{c}$
010	Z_{MAX}/Start
011	Z_{SURF}
012	ΔZ
013	ρ
014	L_c
015	Wind; for Z_1
016	$K = q_r V_B^{2/3}$
017	C_m
018	$K\bar{c}C_m/\cos\alpha$
019	Aero. Mom.
020	Mech. Mom.
021	Extras Mom.
022	L_A
023	D
024	
025	M_{MAX} Count
026	
027	
028	
029	Z_{MAX}
030	R-Repeat
031	Temp.
032	1.6878
033	
034	ρ_0 slug/ft^3
035	Sp. Lift s.L.
036	X^{CP} } Confl
037	y^{CP} } Point
038	a_0
039	a_1

040		
041	$V_B^{2/3}$	
042	V_B	
043	$\Delta\alpha$ Trigger	$\Delta\alpha = \pm.01$ $\Delta x = \pm.1$
044	Prev $\Delta\alpha$	
045	2nd Prev $\Delta\alpha$	
046	$\Delta\alpha$ Trigger	
047	Prev Δw	
048	2nd Prev $\Delta\alpha$	
049		
050	ΣW_{EXTRA}	
051	$\Sigma W_E(x - X^{CP})$	
052	$\Sigma W_C(y - y^{CP})$	
053		
054		
055	$a = dC_L/d\alpha$	
056	$b = Cd\alpha$	
057	$c = dC_D/d\alpha^2$	
058	Temp	
059		
060	$\alpha(=0)$	
061	C_m	#1
062	$dC_m/d\alpha$	
063	α	
064	C_m	#2
065	$dC_m/d\alpha$	
066	α	
067	C_m	#3
068	$dC_m/d\alpha$	
069	α	
070	C_m	#4
071	$dC_m/d\alpha$	
072	α	
073	C_m	#5
074	$dC_m/d\alpha$	
075	α	
076	C_m	#6
077	$dC_m/d\alpha$	
078	α	#7
079	C_m	

080	
081	Z_1
082	Wind$_1$
083	Z_2
084	Wind$_2$
085	Z_3
086	Wind$_3$
087	Z_4
088	Wind$_4$
089	Z_5
090	Wind$_5$
091	Z_6
092	Wind$_6$
093	Z_7
094	Wind$_7$
095	Z_8
096	Wind$_8$
097	Z_9
098	Wind$_9$
099	Z_{10}
100	Wind$_{10}$
101	Z_{11}
102	Wind$_{11}$
103	Z_{12}
104	Wind$_{12}$
105	Z_{13}
106	Wind$_{13}$
107	Reserv. Z_{Set}
108	

3.3.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution.

The balloon, 45,000 CF, was assumed to have an aerodynamic pitching-moment variation with angle-of-attack which could be defined with only 3 points (2 straight lines). No "Extra Weights" were added. A 3-point wind profile from the max altitude, 5500 ft, to the surface, 4000, was also part of the input.

Solutions provided trim angle, total balloon force and angle, and other parameters at 5500, 5000, 4500, and 4000 ft. Option 3 was then exercised to add 275 lb at the confluence point and similar solutions then followed. Note that only the extra weight and its location had to be entered; the other format inputs were printed automatically.

```
PROG.#76.003
TRIM,GEN.BALLOON
        0.04900
        0.10600
        0.00071
CM TABLE
        1.00000
        0.00000
        0.00000

        2.00000
        6.00000
        0.01000

        3.00000
       14.00000
        0.00000

PH.SICAL BALN.
       45000.00
        1000.00
          83.70
          26.60
         -31.90

          57.30*
          -2.50
          30.70
          29.40

          52.20*
           0.00
          25.60
          31.90

          35.10*
           0.30
           8.50
          32.20
```

```
EXTRA WTS.
ENT.¶ IN X IF
NONE
ENT.WT.IN Z
Y IN Y, X IN X
ENT.¶ IN X AFTER
ALL WTS.ENTERED
ALTS.
        5500.00
        4000.00
         500.00
WIND PROFILE
           1.00
        5500.00
          50.00

           2.00
        5000.00
          25.00

           3.00
        4000.00
          15.00

ALT
        5500.00
HEIGHT
        1500.00
WIND
          50.00
DYN.PRES.
           7.21
MECH.MOM.
        6081.72
AERO MOM.
       -6025.60
EXTRAS MOM.
           0.00
SUM OF MOM.
          56.12
TRIM ANGLE
           3.42
CL
           0.17
AERO LIFT
        1529.63
```

```
CD
           0.11
DRAG
        1043.34
CM
           0.01
AERO P.MOM
        4354.76
GROSS LIFT
        2530.17
TOT.LIFT
        4059.80
SUM"EXTRA"WTS
           0.00
TOT.WEIGHT
        1000.00
NET LIFT
        3059.80
TOTAL FORCE
        3232.79
ANGLE TO HORIZON
          71.17


ALT
        5000.00
HEIGHT
        1000.00
WIND
          25.00
DYN.PRES.
           1.83
MECH.MOM.
        4967.41
AERO MOM.
       -4963.24
EXTRAS MOM.
           0.00
SUM OF MOM.
           4.18
TRIM ANGLE
           4.64
CL
           0.23
AERO LIFT
         526.66
```

```
ALT
        4000.00
HEIGHT
           0.00
WIND
          15.00
DYN.PRES.
           0.68
MECH.MOM.
        3546.00
AERO MOM.
       -3533.28
EXTRAS MOM.
           0.00
SUM OF MOM.
          12.72
TRIM ANGLE
           6.19
CL
           0.30
AERO LIFT
         260.57
CD
           0.13
DRAG
         114.43
CM
           0.01
AERO P.MOM
         701.98
GROSS LIFT
        2530.17
TOT.LIFT
        2790.74
SUM"EXTRA"WTS
           0.00
TOT.WEIGHT
        1000.00
NET LIFT
        1790.74
TOTAL FORCE
        1794.39
ANGLE TO HORIZON
          86.34


PROR.SOLVED
J.B.W.  76.003
```

```
ENT.IN X
1 TO START ANEW
2 TO CHANGE BALN
DIM.
3 TO CHG.EXTRAS
4 TO CHG.ALTS.
OR WINDS
           3.00*
VOL,WT,LNGT.HULL
       45000.00
        1000.00
          83.70
EXTRA WTS.
ENT.# IN X IF
NONE
ENT.WT.IN Z
Y IN Y, X IN X
ENT.# IN X AFTER
ALL WTS.ENTERED
         275.00
          26.60
         -31.90

ALTS.,MAX,SURF,
DELTA
        5500.00
        4000.00
         500.00
WIND PROFILE
           1.00*
        5500.00
          50.00

           2.00
        5000.00
          25.00

           3.00
        4000.00
          15.00

ALT
        5500.00
HEIGHT
        1500.00
WIND
          50.00
```

```
DYN.PRES.
           7.21
MECH.MOM.
        6081.72
AERO MOM.
       -6025.60
EXTRAS MOM.
           0.00
SUM OF MOM.
          56.12
TRIM ANGLE
           3.42
CL
           0.17
AERO LIFT
        1529.63
CD
           0.11
DRAG
        1043.34
CM
           0.01
AERO P.MOM
        4354.76
GROSS LIFT
        2530.17
TOT.LIFT
        4059.80
SUM"EXTRA"WTS
         275.00
TOT.WEIGHT
        1275.00
NET LIFT
        2784.80
TOTAL FORCE
        2973.83
ANGLE TO HORIZON
          69.46


ALT
        5000.00
HEIGHT
        1000.00
WIND
          25.00
DYN.PRES.
           1.83
MECH.MOM.
        4967.41
```

3.3.8 NOTES

A. If incorrect data is entered, do not press STOP END to restart program. For proper restart, clearing all registers, press the following

STOP
GO TO
1
7
6
9
CONT

B. Pitching-moment coefficient, C_M table, STOPS 2, 3. See also section on development

1. STOP 2 requires entry of the total number of points used to define the C_M/α curve.
2. STOP 3 requires entry of Point Nos. which should start with 1 for first point where $\alpha = 0$ and proceed to 2, 3, etc, with larger values of α. Last Point No. must equal number entered in STOP 2.
3. Up to a total 7 points may be used to define the C_m/α curve.
4. If for example, 6 points are used to define the curve, 5 slopes, $dC_m/d\alpha$ are thereby available for calculation of C_m at any α. The slope between Point Nos. 5 and 6 is assumed to extend beyond Point No. 6

C. Extra Weight Entries, STOP 9

1. The payload weight can be included here if desired as will not affect the trim angle if located at the confluence point:

	(X)	(Y)	(z)
STOP 9-9-9	X^{CP}	Y^{CP}	Wt_p

It will affect the net lift and hence the total force and its angle.

2. Other extra weights locations will also affect the trim. Due to the make up of the program do not make the X location of any weight equal to π. X locations can carry a negative sign if ahead of the nose of the balloon. A negative-Y indicates a position below the centerline of the balloon.

D. Wind Profile Entries, STOP 11

1. First entry must be Point No. 1, with $Z = Z_{max}$ (Ballonet empty condition).

2. Up to 12 more altitude-wind points may be entered to define the wind profile from Z_{max} to Z_{surf}.
3. The last entry must be for Z_{surf}.

3.4 Program 76.004 – FAMILY-2 Tethered Balloon Trim, Single Altitude, Design Condition: Ballonet Empty

3.4.1 GENERAL DESCRIPTION

A type of tethered balloon, called the FAMILY-2 has an aerodynamic shaped hull and two vertical and two horizontal fins. During its development, model wind-tunnel and full-scale static and flight tests were made in extensive detail. References 1 and 2 provide a sufficient amount of information on a 200,000 CF system to write a trim equation with more exact constants than any other balloon now available.

Program Nos. 76.004 (and 76.005) were approached with the idea of providing a quick solution to trim problems as well as inputs to the tether-cable program. They were tailored for a 45,000 CF balloon which the AFGL will receive in 1976. However, they can be easily converted into a completely general program as explained in Section 3.4.8. Program No. 76.004 is concerned with the condition where the balloon is completely filled with gas, that is, its ballonet is empty. It will be called the design condition. Program No. 76.005 was designed to accommodate both the design condition as well as other conditions at lower altitudes where the ballonet is in various stages of air inflation.

Due to the extensive measurements made with the 200,000 CF FAMILY-2 balloon by the Range Measurements Lab of the Air Force Eastern Test Range, it was possible to obtain data which allowed use of the balloon aerodynamic center-of-pressure. Like the neutral-point, it is defined as the point where the pitching-moment is zero. This permits elimination of one term in the moment equation developed under Program No. 76.003 where a fixed aerodynamic center was utilized. The longitudinal variation of CP with trim angle was computed in non-dimensional form.

Since the RML balloon features a large windscreen to cover its payload and the more general balloon being obtained does not have a windscreen, the differences in aerodynamic characteristics had to be obtained from wind-tunnel tests of the two designs. Since flight data differed significantly from wind-tunnel data, the delta windscreen effects were applied to the flight data to obtain the full-scale aerodynamic characteristics of a FAMILY-2 balloon without windscreen.

The center of buoyancy locations were non-dimensionalized from flight measurements of the RML balloon assuming that the windscreen has no effect. The vertical location is a straight-line function of true angle-of-attack. However, the longitudinal location is a function of both trim angle and ballonet fullness. For

1. Yon, T. H. (1974) Design Verification if the IID-7A Balloon, Test Program Report TR No. 74-058, RCA Service Co. for Range Measurements Laboratory, Air Force Eastern Test Range, Patric AFB, Florida, 2 Volumes.
2. Schjeldahl, G.T. Co. (1971) Wind Tunnel Test Results Family IID Aerodynamically Shaped Balloon, 5 Volumes.

this case, of an empty ballonet, a curve-fit with a correlation of 0.99 was possible. This fit is used in Program No. 76.004, the design condition.

3.4.2 DEVELOPMENT OF PROGRAM AND EQUATIONS

This case covers a specific tethered balloon type wherein:

a. The location of the aerodynamic center of pressure ($C_M = 0$) is known and can be utilized rather than an arbitrary fixed aerodynamic reference center ($C_M \neq 0$).

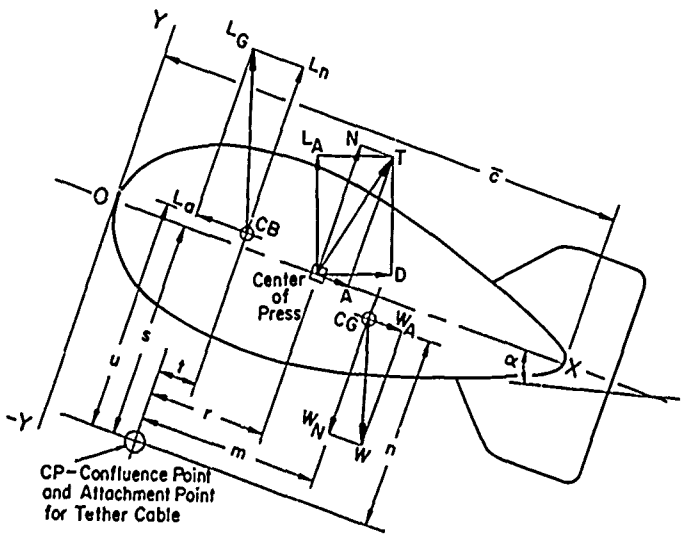
b. The fore and aft location of the center of pressure varies with angle of attack.

c. The location of the center of buoyancy varies with ν.

d. The balloon will be flown only at its design altitude condition (ballonet empty).

A. The object of the program is to determine the trim conditions of the balloon and the total force and its angle which must be resisted by the tether-cable. The tether-cable is attached at the confluence point of the multiple flying-lines attached to the balloon's skin. Hence at trim:

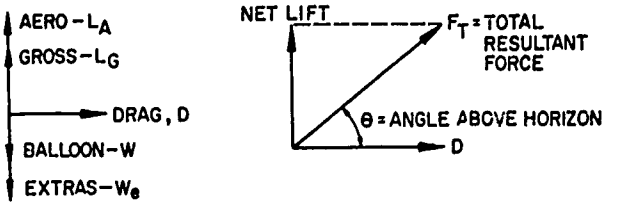
Σ Moments at Confluence Point = 0
Positive moments are clockwise



The moment Eq. (10) developed for Program 76.003 in Section 3.3.2 is applicable here provided the aerodynamic pitching-moment is removed. The equation then becomes:

$$0 = mW - tL + \tan\alpha\,(nW - uL) \qquad \text{(Mech. Mom.)}$$
$$- K\,[ra\,\alpha - sb - sc\alpha^2 + \tan\alpha\,(sa\,\alpha + rb + rc\alpha^2)] \qquad \text{(Aero Mom.)}$$
$$+ \cos\alpha\,[\Sigma W_e\,(x - x^{CP}) + \tan\alpha\,\Sigma W_e\,(y - y^{CP})] \qquad \text{(Extras Mom)}$$

B. After solving for α_{trim} the Aero Lift (L_A) and Drag, can be calculated and used with buoyancy and Mass terms to obtain total Resultant Force (F_T) and (θ) at the Confluence Point



C. Use 2 constant form for density ratio (same in all programs)

$$\frac{\ln \rho/\rho_o}{Z} = a_o + a_1 Z$$

where

$$a_1 = -1.7772^{-10}$$
$$a_o = -2.81361^{-5}$$

D. For 45,000 CF Balloon, let

$X_{CG} = 57.3$ ft
$Y_{CG} = -2.5$
$X^{CP} = 26.6$
$Y^{CP} = -31.9$
$s = 31.9$
$\overline{c} = 83.7$

Built into program. See Notes to change to entry quantities or to change values

CG Location assumed unchanged with α variation. RML tests for CG were made with empty ballonet and therefore best for design condition.

E. Center of Buoyancy - Empty Ballonet

Y_{CB} for 200,000 CF balloon = 0.5

Hull length, $\bar{c}$ for 200,000 CF balloon = 137.58

$Y_{CB}/\bar{c} = .003634$

From fit of data in Reference 1 for empty ballonet case

$$X_{CB}/\bar{c} = a_o + a_1 \alpha + a_2 \alpha^2$$

where

$$a_o = .426185$$
$$a_1 = -.00110645$$
$$a_2 = .0000438942$$

F. Aero Coefficients - Flight data corrected for no windscreen by difference in wind-tunnel data with and without wind screen

a. $C_L = .049\,\alpha$ or $dC_L/d\alpha$ 049

b. $C_D = .106 + .00071\alpha^2 = {}'C_{D_O} + \frac{dC_D}{d\alpha^2}\,\alpha^2$

$C_{D_O} = .106$ = minimum drag at $\alpha = 0$

$dC_D/d\alpha^2 = .00071$

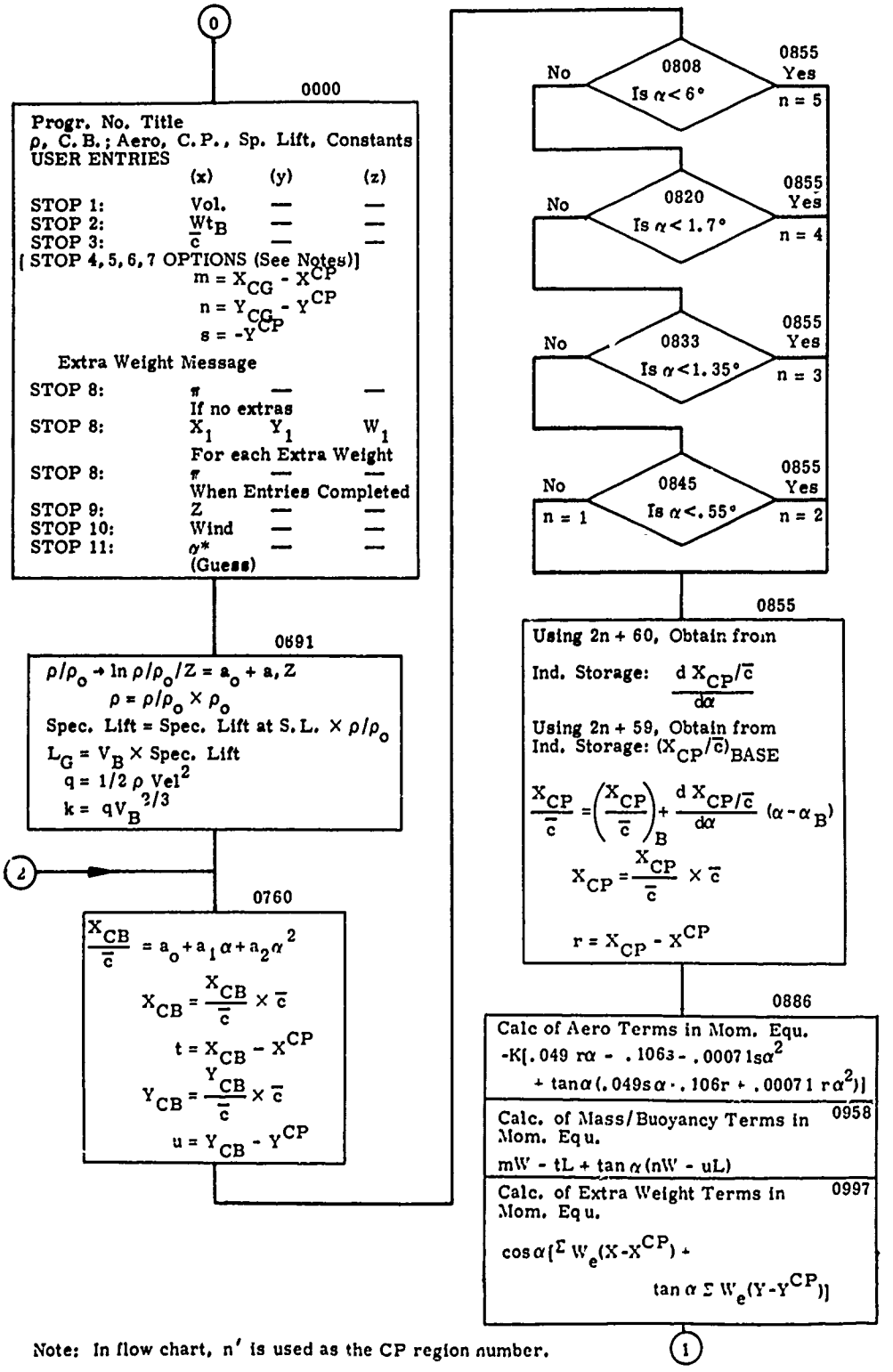
c. $\frac{Y_{CP}}{\bar{c}} = 0$

d. $\frac{X_{CP}}{\bar{c}}$ from W.T. tests w/o windscreen. A series of straight lines is used to define the variation of $X_{CP}/\bar{c}$ with

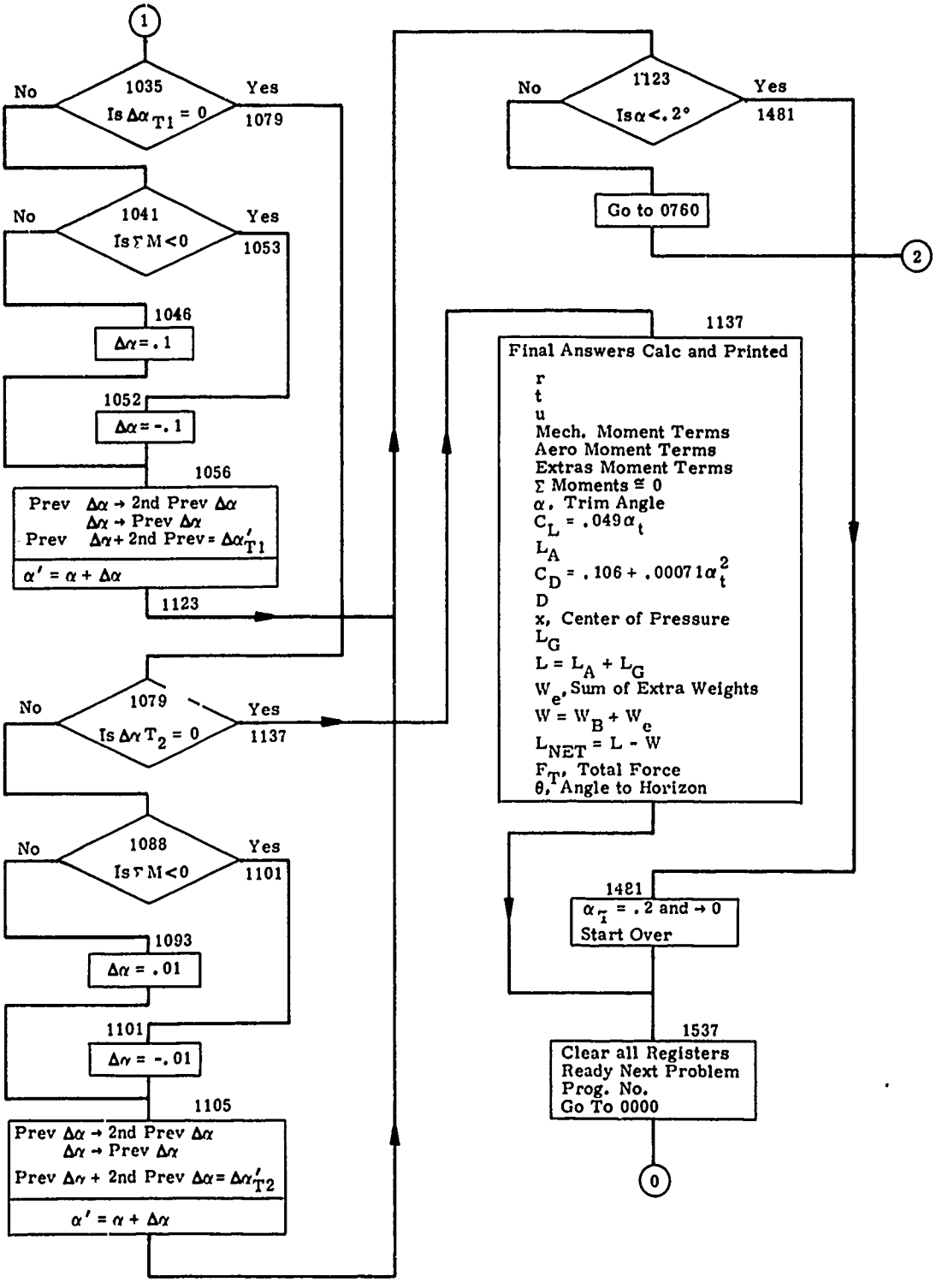
Region	α Base	$(\frac{X_{CP}}{c})$ Base	$\frac{d\frac{X_{CP}}{c}}{d\alpha}$	α Range
1	0	.657	.2691	0 - .55
2	.55	.805	-.4350	.55 - 1.35
3	1.35	.457	.1229	1.35 - 1.7
4	1.7	.50	.01395	1.7 - 6.0
5	6.0 26.0	.56 .634	.00370	6.0

$$\frac{X_{CP}}{\bar{c}} = (\frac{X_{CP}}{\bar{c}})_{\text{Base}} + \frac{d\frac{X_{CP}}{\bar{c}}}{d\alpha} (\alpha - \alpha_{\text{Base}})$$

3.4.3. FLOW CHART



Note: In flow chart, n′ is used as the CP region number.


1
1035
Is $\Delta\alpha_{T1} = 0$
No
Yes
1079
1041
Is $\Sigma M < 0$
No
Yes
1053
1046
$\Delta\alpha = .1$
1052
$\Delta\alpha = -.1$
1056
Prev $\Delta\alpha \rightarrow$ 2nd Prev $\Delta\alpha$
$\Delta\alpha \rightarrow$ Prev $\Delta\alpha$
Prev $\Delta\alpha$ + 2nd Prev = $\Delta\alpha'_{T1}$
$\alpha' = \alpha + \Delta\alpha$
1123
1079
Is $\Delta\alpha T_2 = 0$
No
Yes
1137
1088
Is $\Sigma M < 0$
No
Yes
1101
1093
$\Delta\alpha = .01$
1101
$\Delta\alpha = -.01$
1105
Prev $\Delta\alpha \rightarrow$ 2nd Prev $\Delta\alpha$
$\Delta\alpha \rightarrow$ Prev $\Delta\alpha$
Prev $\Delta\alpha$ + 2nd Prev $\Delta\alpha = \Delta\alpha'_{T2}$
$\alpha' = \alpha + \Delta\alpha$
1123
Is $\alpha < .2°$
No
Yes
1481
Go to 0760
2
1137
Final Answers Calc and Printed
r
t
u
Mech. Moment Terms
Aero Moment Terms
Extras Moment Terms
Σ Moments $\cong 0$
α, Trim Angle
$C_L = .049\alpha_t$
L_A
$C_D = .106 + .00071\alpha_t^2$
D
x, Center of Pressure
L_G
$L = L_A + L_G$
W_e, Sum of Extra Weights
$W = W_B + W_e$
$L_{NET} = L - W$
F_T, Total Force
θ_T, Angle to Horizon
1481
$\alpha_T = .2$ and $\rightarrow 0$
Start Over
1537
Clear all Registers
Ready Next Problem
Prog. No.
Go To 0000
0

3.4.4 OPERATING INSTRUCTIONS

KEY STROKES		ENTRIES		PRINTS
RUN				
END				
FIX, 2, 3----				(No. of desired decimal places)
CONT	(X)	(Y)	(Z)	Program No. and Title
Stop 1, Enter:	V_B	-	-	
CONT				V_B, Balloon Volume, CF
Stop 2, Enter:	W_B	-	-	
CONT				W_B, Balloon Weight, lb
Stop 3, Enter:	$\bar{c}$	-	-	
CONT				$\bar{c}$, Length, Hull, ft
(Stops 4, 5, 6, and 7 not in program as written. See notes for optional use of these for X^{CP}, Y^{CP}, X_{CG}, AND Y_{CG})				
				X - CONF. PT. X^{CP}
				Y - CONF. PT. Y^{CP}
				X, Y CG-M, N, S X_{CG} Y_{CG} m n s
				Directions for "Extra" weights: Ent Π in X, if None. Ent Wt inZ, y in Y, x in X. Ent Π in X when all entries made.
Stop 8, Enter Π or:	X_1	Y_1	W_1	
CONT				W_1 (if entered) Y_1 (if entered) X_1 (if entered)
(Stop 8 repeats until closing Π is entered)				
Stop 9, Enter:	Z	-	-	
CONT				Z, Alt, ft
Stop 10, Enter:	W	-	-	
CONT				W, Wind, Knots
Stop 11, Enter:	α	-	-	
CONT				α, Guess trim angle, deg

(Program begins computations)

DYN PRES, q, lb/ft^2

In α-trim loop, a pause at Step 1125, displays α in X reg., and Moments in Z reg. as search is made for α-trim where Σ Moments = 0. When found, printouts then occur as follows:

R
r, ft
T
t, ft
U
u, ft
MECH. MOM.
Values of Mech Moment, ft-lb
AERO MOM.
Value of Aero Moment, ft-lb
EXTRAS MOM.
Value of Extras Moment, ft-lb
SUM of MOM.
Σ Moments $\cong$ 0
TRIM ANGLE ATCK
α, deg
CL
C_L
AERO LIFT
L_A, lb
CD
C_D
DRAG
D, lb
X-CENTER PRESS
X_{CP}, ft
GROSS BUOY. LIFT
L_G, lb
TOT. LIFT
$L = L_A + L_G$, lb
SUM "EXTRA" WTS
ΣW_{extra}, lb
TOT. WEIGHT
$W = W_B + \Sigma W_{extra}$, lb
NET LIFT
$L_N = L - W$, lb
TOTAL FORCE
$F_T = \sqrt{L_N^2 + D^2}$, lb
ANGLE TO HORIZON
θ = arc tan L_N/D, deg
READY NEXT PROB.
J.B.W. 76.004

A new set of data can now be entered at first stop in program after repeat of Title and Number.

3.4.5. SAMPLE INPUT DATA FORM

INPUT			76.002, 76.003, 76.004, and 76.005			
			76.003, 76.004, 76.005 EXTRA WEIGHT TABLE		76.003 and 76.005 WIND PROFILE*	
Balloon Volume	V_B	cu ft	W_1	lb	No. 1	1
Ballonet Volume	v	cu ft	Y_1	ft	Z_{MAX}, ft MSL	
Balloon Weight	W_B	lb	X_1	ft	Wind, knots	
Hull Length	$\bar{c}$	ft	W_2		No. 2	2
① Location of Confluence Pt.	Y^{CP}	ft	Y_2		Z_2	
	X^{CP}	ft	X_2		$Wind_2$	
① Location of Center of Gravity	Y^{CG}	ft	W_3		No. 3	3
	X^{CG}	ft	Y_3		Z_3	
② Location of Center of Buoyancy	Y^{CB}	ft	X_3		$Wind_3$	
	X^{CB}	ft	W_4		No. 4	4
① Location of Aero Reference Center	Y^{ARC}	ft	Y_4		Z_4	
	X^{ARC}	ft	X_4		$Wind_4$	
Altitude, Max	Z_M	ft	W_5		No. 5	5
Altitude, Surf	Z_S	ft	Y_5		Z_5	
Increment of Alt	ΔZ	ft	X_5		$Wind_5$	
③ $dC_L/d\sigma$	a		W_6		No. 6	6
③ C_{D_O}	b		Y_6		Z_6	
③ $dC_D/d\sigma^2$	c		X_6		$Wind_6$	
③ C_M TABLE*			W_7		No. 7	7
NO. 1	1		Y_7		Z_7	
α_1	0	deg	X_7		$Wind_7$	
C_{M1}			W_8		No. 8	8
NO. 2	2		Y_8		Z_8	
α_2		deg	X_8		$Wind_8$	
C_{M2}			W_9		No. 9	9
NO. 3	3		Y_9		Z_9	
α_3		deg	X_9		$Wind_9$	
C_{M3}			W_{10}		No. 10	10
NO. 4	4		Y_{10}		Z_{10}	
α_4		deg	X_{10}		$Wind_{10}$	
C_{M4}			W_{11}		No. 11	11
NO. 5	5		Y_{11}		Z_{11}	
α_5		deg	X_{11}		$Wind_{11}$	
C_{M5}			W_{12}		No. 12	12
NO. 6	6		Y_{12}		Z_{12}	
α_6		deg	X_{12}		$Wind_{12}$	
C_{M6}			W_{13}		No. 13	13
NO. 7	7		Y_{13}		Z_{13}	
α_7		deg	X_{13}		$Wind_{13}$	
C_{M7}						

① See Note 76.003
② Req'd for 76.002 and 76.003
③ Req'd for 76.003 only
* A minimum of two points must be used, a maximum of seven points may be used. First point must be for $\alpha = 0°$

Any number of "extra" weights may be used. One entry can be Instrument Package and Payload. If these are at Confluence Point make
$Y = Y^{CP}$
$X = X^{CP}$

*A minimum of 2 Points must be used and a maximum of 13 may be used. First must be Z_{MAX} and last must be Z_{SURF}. 76.004 requires one value of wind.

3.4.6 PROGRAM 76.004 - TRIM, FAMILY-2, SINGLE DESIGN ALTITUDE

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0000	CLR	0050	7	0100	CHS	0150	7	0200	2	0250	XTO
0001	FMT	0051	7	0101	XTO	0151	1	0201	2	0251	0
0002	FMT	0052	7	0102	0	0152	XTO	0202	9	0252	4
0003	π	0053	1	0103	3	0153	0	0203	XTO	0253	8
0004	a	0054	7	0104	7	0154	2	0204	0	0254	0
0005	D	0055	CHS	0105	.	0155	1	0205	6	0255	XTO
0006	G	0056	EEX	0106	0	0156	.	0206	6	0256	4
0007	.	0057	1	0107	0	0157	6	0207	.	0257	4
0008	GTO	0058	0	0108	1	0158	5	0208	5	0258	XTO
0009	7	0059	CHS	0109	1	0159	7	0209	XTO	0259	4
0010	6	0060	XTO	0110	0	0160	XTO	0210	0	0260	7
0011	.	0061	0	0111	6	0161	0	0211	6	0261	XTO
0012	0	0062	3	0112	4	0162	6	0212	7	0262	5
0013	0	0063	9	0113	5	0163	1	0213	.	0263	0
0014	4	0064	2	0114	CHS	0164	.	0214	0	0264	XTO
0015	CLR	0065	.	0115	XTO	0165	2	0215	1	0265	5
0016	XTO	0066	8	0116	0	0166	6	0216	3	0266	1
0017	a	0067	1	0117	3	0167	9	0217	9	0267	XTO
0018	I	0068	3	0118	6	0168	1	0218	5	0268	0
0019	M	0069	6	0119	.	0169	XTO	0219	XTO	0269	5
0020	CLX	0070	0	0120	0	0170	0	0220	0	0270	2
0021	D	0071	6	0121	0	0171	6	0221	6	0271	.
0022	E	0072	CHS	0122	3	0172	2	0222	8	0272	0
0023	YTO	0073	EEX	0123	6	0173	.	0223	.	0273	6
0024	I	0074	5	0124	3	0174	8	0224	5	0274	5
0025	G	0075	CHS	0125	4	0175	0	0225	6	0275	9
0026	N	0076	XTO	0126	XTO	0176	5	0226	XTO	0276	8
0027	CNT	0077	0	0127	0	0177	XTO	0227	0	0277	8
0028	A	0078	3	0128	4	0178	0	0228	6	0278	XTO
0029	L	0079	8	0129	0	0179	6	0229	9	0279	0
0030	XTO	0080	.	0130	.	0180	3	0230	.	0280	3
0031	.	0081	4	0131	0	0181	.	0231	0	0281	4
0032	F	0082	2	0132	4	0182	4	0232	0	0282	.
0033	A	0083	6	0133	9	0183	3	0233	3	0283	0
0034	M	0084	1	0134	XTO	0184	5	0234	7	0284	0
0035	.	0085	8	0135	0	0185	CHS	0235	XTO	0285	2
0036	2	0086	5	0136	1	0186	XTO	0236	0	0286	3
0037	CHT	0087	XTO	0137	9	0187	0	0237	7	0287	7
0038	XTO	0088	0	0138	.	0188	6	0238	0	0288	8
0039	.	0089	3	0139	1	0189	4	0239	1	0289	XTO
0040	B	0090	5	0140	0	0190	.	0240	1	0290	0
0041	A	0091	.	0141	6	0191	4	0241	XTO	0291	1
0042	L	0092	4	0142	XTO	0192	5	0242	4	0292	2
0043	L	0093	3	0143	0	0193	7	0243	3	0293	FMT
0044	O	0094	8	0144	2	0194	XTO	0244	XTO	0294	FMT
0045	O	0095	9	0145	0	0195	0	0245	4	0295	INT
0046	N	0096	4	0146	.	0196	6	0246	5	0296	0
0047	FMT	0097	2	0147	0	0197	5	0247	XTO	0297	L
0048	1	0098	EEX	0148	0	0198	.	0248	4	0298	.
0049	.	0099	4	0149	0	0199	1	0249	6	0299	FMT

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0300	1	0350	FMT	0400	C	0450	α	0500	N	0550	π
0301	STP	0351	FMT	0401	G	0451	A	0501	D	0551	X=Y
0302	PNT	0352	YE	0402	-	0452	CNT	0502	CNT	0552	0
0303	XTO	0353	-	0403	CLX	0453	IND	0503	YE	0553	6
0304	4	0354	C	0404	N	0454	XTO	0504	CNT	0554	.
0305	2	0355	0	0405	CLX	0455	YTO	0505	I	0555	2
0306	UP	0356	N	0406	N	0456	CLR	0506	N	0556	b
0307	2	0357	F	0407	CLX	0457	E	0507	CNT	0557	RUP
0308	UP	0358	.	0408	YTO	0458	N	0508	YE	0558	PNT
0309	3	0359	π	0409	FMT	0459	XTO	0509	CLR	0559	XTO
0310	DIV	0360	XTO	0410	5	0460	.	0510	E	0560	b
0311	DN	0361	.	0411	7	0461	CHS	0511	N	0561	XTO
0312	XEY	0362	FMT	0412	.	0462	CNT	0512	XTO	0562	+
0313	H	0363	2	0413	3	0463	I	0513	.	0563	5
0314	XTO	0364	6	0414	PNT	0464	N	0514	CHS	0564	0
0315	4	0365	.	0415	RUP	0465	CNT	0515	CNT	0565	DN
0316	1	0366	6	0416	-	0466	YE	0516	I	0566	PNT
0317	FMT	0367	PNT	0417	2	0467	CLR	0517	N	0567	XEY
0318	FMT	0368	XTO	0418	.	0468	0	0518	CNT	0568	PNT
0319	IND	0369	5	0419	5	0469	XTO	0519	YE	0569	PNT
0320	E	0370	4	0420	CHS	0470	H	0520	CNT	0570	UP
0321	I	0371	UP	0421	PNT	0471	E	0521	A	0571	XFR
0322	G	0372	FMT	0422	RUP	0472	α	0522	F	0572	5
0323	H	0373	FMT	0423	-	0473	IND	0523	XTO	0573	4
0324	XTO	0374	XFR	0424	RUP	0474	I	0524	E	0574	-
0325	FMT	0375	-	0425	XTO	0475	YTO	0525	α	0575	XFR
0326	2	0376	C	0426	3	0476	E	0526	E	0576	5
0327	STP	0377	0	0427	PNT	0477	CLX	0527	N	0577	5
0328	PNT	0378	N	0428	RUP	0478	E	0528	XTO	0578	RUP
0329	XTO	0379	F	0429	PNT	0479	N	0529	α	0579	XEY
0330	1	0380	.	0430	XTO	0480	XTO	0530	I	0580	-
0331	FMT	0381	π	0431	4	0481	E	0531	E	0581	b
0332	FMT	0382	XTO	0432	RUP	0482	α	0532	YTO	0582	X
0333	L	0383	FMT	0433	CHS	0483	CLR	0533	CNT	0583	YTO
0334	E	0384	3	0434	PNT	0484	IND	0534	C	0584	+
0335	N	0385	1	0435	XTO	0485	XTO	0535	0	0585	5
0336	G	0386	.	0436	6	0486	.	0536	N	0586	2
0337	XTO	0387	9	0437	CNT	0487	I	0537	π	0587	RUP
0338	H	0388	CHS	0438	CNT	0488	N	0538	L	0588	Σ
0339	CNT	0389	PNT	0439	FMT	0489	CNT	0539	E	0589	YTO
0340	H	0390	XTO	0440	FMT	0490	XSO	0540	XTO	0590	+
0341	1/X	0391	5	0441	I	0491	CLX	0541	E	0591	0
0342	L	0392	5	0442	F	0492	XFR	0542	FMT	0592	5
0343	L	0393	UP	0443	CNT	0493	CNT	0543	8	0593	1
0344	FMT	0394	FMT	0444	N	0494	I	0544	UP	0594	8
0345	3	0395	FMT	0445	0	0495	N	0545	UP	0595	UP
0346	STP	0396	YE	0446	CNT	0496	CNT	0546	STP	0596	UP
0347	PNT	0397	CLX	0447	E	0497	XFR	0547	YTO	0597	STP
0348	XTO	0398	XFR	0448	YE	0498	CLR	0548	b	0598	YTO
0349	8	0399	CNT	0449	XTO	0499	A	0549	XEY	0599	b

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0600	--RCY	0650	--STP	0700	--XFR	0750	--XFR	0800	-- 0	0850	-- 1
0601	-- π	0651	--PNT	0701	-- 3	0751	-- N	0801	-- 3	0851	--RUP
0602	--X=Y	0652	-- UP	0702	-- 8	0752	-- .	0802	-- 3	0852	--RUP
0603	-- 0	0653	-- 1	0703	-- +	0753	-- π	0803	-- 5	0853	--XEY
0604	-- 6	0654	-- .	0704	-- DN	0754	-- α	0804	-- UP	0854	-- 0
0605	-- 1	0655	-- 6	0705	-- X	0755	-- E	0805	-- α	0855	-- -
0606	-- 2	0656	-- 8	0706	-- DN	0756	--YTO	0806	-- UP	0856	-- 2
0607	--GTO	0657	-- 7	0707	-- J	0757	--YTO	0807	-- 6	0857	--RUP
0608	-- 0	0658	-- 8	0708	-- UP	0758	--FNT	0808	--X<Y	0858	-- X
0609	-- 5	0659	-- X	0709	-- UP	0759	--PNT	0809	-- 0	0859	-- 6
0610	-- 5	0660	--YTO	0710	--XFR	0760	-- α	0810	-- 8	0860	-- 0
0611	-- 6	0661	-- 1	0711	-- 1	0761	-- UP	0811	-- 5	0861	-- +
0612	-- 9	0662	-- 1	0712	-- 2	0762	--XSQ	0812	-- 5	0862	--YTO
0613	-- UP	0663	--FNT	0713	-- X	0763	-- UP	0813	-- 1	0863	-- 6
0614	-- UP	0664	--FNT	0714	--YTO	0764	--XFR	0814	-- .	0864	--XFR
0615	--FNT	0665	-- G	0715	-- 1	0765	-- 3	0815	-- 7	0865	--IND
0616	--FNT	0666	--1/X	0716	-- 3	0766	-- 7	0816	--RUP	0866	-- 6
0617	-- A	0667	-- E	0717	-- DN	0767	-- X	0817	-- 4	0867	--RUP
0618	-- L	0668	--YTO	0718	--XFR	0768	--XFR	0818	--RUP	0868	-- X
0619	--XTO	0669	--YTO	0719	-- 3	0769	-- 3	0819	--RUP	0869	-- 1
0620	-- .	0670	--CNT	0720	-- 4	0770	-- 6	0820	--X<Y	0870	--XTO
0621	-- F	0671	--XTO	0721	-- X	0771	--RUP	0821	-- 0	0871	-- -
0622	--XTO	0672	-- α	0722	--XFR	0772	-- X	0822	-- 8	0872	-- 6
0623	-- .	0673	-- I	0723	-- 4	0773	--XFR	0823	-- 5	0873	--XFR
0624	-- M	0674	-- M	0724	-- 2	0774	-- 3	0824	-- 5	0874	--IND
0625	--YTO	0675	--CNT	0725	-- X	0775	-- 5	0825	-- 1	0875	-- 6
0626	-- L	0676	-- A	0726	--YTO	0776	-- +	0826	-- .	0876	-- +
0627	--FNT	0677	-- N	0727	-- 2	0777	-- DN	0827	-- 3	0877	--XFR
0628	--STP	0678	-- G	0728	--XFR	0778	-- +	0828	-- 5	0878	-- 8
0629	--PNT	0679	-- L	0729	-- 1	0779	--XFR	0829	--RUP	0879	-- X
0630	--XTO	0680	-- E	0730	-- 1	0780	-- 8	0830	-- 3	0880	--XFR
0631	-- 1	0681	--FNT	0731	--XSQ	0781	-- X	0831	--RUP	0881	-- 5
0632	-- 0	0682	-- 1	0732	-- UP	0782	--XFR	0832	--RUP	0882	-- 4
0633	--FNT	0683	-- 1	0733	--XFR	0783	-- 5	0833	--X<Y	0883	-- -
0634	--FNT	0684	-- UP	0734	-- 1	0784	-- 4	0834	-- 0	0884	--YTO
0635	--IND	0685	-- UP	0735	-- 3	0785	-- -	0835	-- 8	0885	-- 5
0636	-- I	0686	--STP	0736	-- X	0786	--YTO	0836	-- 5	0886	-- α
0637	-- N	0687	--PNT	0737	-- 2	0787	-- 7	0837	-- 5	0887	--XSQ
0638	-- D	0688	--PNT	0738	--DIV	0788	--XFR	0838	-- .	0888	-- X
0639	--CLX	0689	--XTO	0739	--XFR	0789	-- 4	0839	-- 5	0889	--XFR
0640	-- K	0690	-- α	0740	-- 4	0790	-- 0	0840	-- 5	0890	-- 2
0641	-- N	0691	--XFR	0741	-- 1	0791	-- UP	0841	--RUP	0891	-- 1
0642	-- 0	0692	-- 1	0742	--XEY	0792	--XFR	0842	-- 2	0892	-- X
0643	--XTO	0693	-- 0	0743	-- X	0793	-- 8	0843	--RUP	0893	--XFR
0644	--YTO	0694	-- UP	0744	--YTO	0794	-- X	0844	--RUP	0894	-- 6
0645	--FNT	0695	-- UP	0745	-- 1	0795	--XFR	0845	--X<Y	0895	-- UP
0646	-- 1	0696	--XFR	0746	-- 4	0796	-- 5	0846	-- 0	0896	--XFR
0647	-- 0	0697	-- 3	0747	--FNT	0797	-- 5	0847	-- 8	0897	-- 1
0648	-- UP	0698	-- 9	0748	--FNT	0798	-- -	0848	-- 5	0898	-- 9
0649	-- UP	0699	-- X	0749	-- D	0799	--YTO	0849	-- 5	0899	-- X

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0900	α	0950	-	1000	UP	1050	0	1100	5	1150	PRT
0901	X	0951	XFR	1001	α	1051	5	1101	.	1151	FIX
0902	DN	0952	1	1002	0	1052	6	1102	0	1152	FIX
0903	XEY	0953	4	1003	X	1053	.	1103	1	1153	1/X
0904	+	0954	X	1004	XFR	1054	1	1104	CHS	1154	FIX
0905	XFR	0955	YTO	1005	5	1055	CHS	1105	UP	1155	XFR
0906	5	0956	2	1006	1	1056	UP	1106	XFR	1156	.3
0907	UP	0957	9	1007	+	1057	XFR	1107	4	1157	3
0908	XFR	0958	XFR	1008	α	1058	4	1108	7	1158	PRT
0909	2	0959	1	1009	N	1059	4	1109	XTO	1159	PRT
0910	0	0960	UP	1010	X	1060	XTO	1110	4	1160	FIX
0911	X	0961	XFR	1011	YTO	1061	4	1111	8	1161	FIX
0912	DN	0962	3	1012	3	1062	5	1112	YTO	1162	M
0913	+	0963	X	1013	1	1063	YTO	1113	4	1163	E
0914	α	0964	XFR	1014	XFR	1064	4	1114	7	1164	C
0915	0	0965	2	1015	3	1065	4	1115	XEY	1165	H
0916	X	0966	UP	1016	0	1066	XEY	1116	+	1166	.
0917	YTO	0967	XFR	1017	+	1067	+	1117	YTO	1167	M
0918	b	0968	7	1018	XFR	1068	YTO	1118	4	1168	0
0919	α	0969	X	1019	2	1069	4	1119	6	1169	M
0920	UP	0970	DN	1020	9	1070	3	1120	XEY	1170	E
0921	XFR	0971	-	1021	CHS	1071	XEY	1121	α	1171	H
0922	5	0972	YTO	1022	+	1072	α	1122	+	1172	XTO
0923	X	0973	b	1023	XTO	1073	+	1123	YTO	1173	FIX
0924	XFR	0974	XFR	1024	2	1074	GTO	1124	α	1174	XFR
0925	1	0975	1	1025	9	1075	1	1125	PSE	1175	3
0926	9	0976	UP	1026	YTO	1076	1	1126	.	1176	0
0927	X	0977	XFR	1027	0	1077	2	1127	2	1177	PRT
0928	α	0978	4	1028	3	1078	3	1128	X>Y	1178	FIX
0929	XSQ	0979	X	1029	2	1079	XFR	1129	1	1179	FIX
0930	UP	0980	XFR	1030	0	1080	4	1130	4	1180	A
0931	XFR	0981	2	1031	UP	1081	6	1131	8	1181	E
0932	C	0982	UP	1032	XFR	1082	X=Y	1132	1	1182	α
0933	X	0983	XFR	1033	4	1083	1	1133	GTO	1183	0
0934	XFR	0984	3	1034	3	1084	1	1134	7	1184	.
0935	2	0985	3	1035	X=Y	1085	3	1135	6	1185	M
0936	'	0986	X	1036	1	1086	7	1136	0	1186	0
0937	X	0987	DN	1037	0	1087	DN	1137	FIX	1187	M
0938	DN	0988	-	1038	7	1088	X>Y	1138	FIX	1188	.
0939	-	0989	α	1039	9	1089	1	1139	α	1189	FIX
0940	XFR	0990	0	1040	DN	1090	1	1140	FIX	1190	XFR
0941	6	0991	X	1041	X>Y	1091	0	1141	XFR	1191	2
0942	UP	0992	b	1042	1	1092	1	1142	5	1192	9
0943	XFR	0993	+	1043	0	1093	.	1143	PRT	1193	PRT
0944	2	0994	YTO	1044	5	1094	0	1144	FIX	1194	FIX
0945	0	0995	3	1045	3	1095	1	1145	FIX	1195	FIX
0946	X	0996	0	1046	.	1096	GTO	1146	XTO	1196	E
0947	DN	0997	XFR	1047	1	1097	1	1147	FIX	1197	YE
0948		0998	5	1048	GTO	1098	1	1148	XFR	1198	XTO
0949	b	0999	2	1049	1	1099	C	1149	7	1199	α

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1200	A	1250	F	1300	X	1350	G	1400	UP	1450	α
1201	YTO	1251	FMT	1301	FMT	1351	α	1401	XFR	1451	C
1202	CHT	1252	PMT	1302	FMT	1352	0	1402	1	1452	E
1203	N	1253	FMT	1303	C	1353	YTO	1403	+	1453	FMT
1204	0	1254	FMT	1304	D	1354	YTO	1404	DN	1454	PMT
1205	N	1255	C	1305	FMT	1355	CHT	1405	FMT	1455	KEY
1206	.	1256	L	1306	PMT	1356	L	1406	FMT	1456	FMT
1207	FMT	1257	FMT	1307	DN	1357	I	1407	XTO	1457	FMT
1208	XFR	1258	UP	1308	FMT	1358	F	1408	0	1458	A
1209	3	1259	XSQ	1309	FMT	1359	XTO	1409	XTO	1459	N
1210	1	1260	XEY	1310	D	1360	FMT	1410	A	1460	G
1211	PMT	1261	UP	1311	α	1361	PMT	1411	L	1461	L
1212	FMT	1262	XFR	1312	A	1362	UP	1412	CHT	1462	E
1213	FMT	1263	1	1313	G	1363	b	1413	IND	1463	CHT
1214	YTO	1264	9	1314	FMT	1364	+	1414	E	1464	XTO
1215	1/X	1265	X	1315	PMT	1365	DN	1415	I	1465	0
1216	N	1266	XFR	1316	XTO	1366	FMT	1416	G	1466	CHT
1217	CHT	1267	1	1317	4	1367	FMT	1417	H	1467	H
1218	0	1268	4	1318	9	1368	XTO	1418	XTO	1468	0
1219	F	1269	XEY	1319	FMT	1369	0	1419	FMT	1469	α
1220	CHT	1270	X	1320	FMT	1370	XTO	1420	PMT	1470	I
1221	N	1271	PMT	1321	YE	1371	.	1421	-	1471	XSQ
1222	0	1272	DN	1322	-	1372	L	1422	XFR	1472	0
1223	N	1273	XTO	1323	C	1373	I	1423	4	1473	N
1224	E	1274	b	1324	E	1374	F	1424	9	1474	FMT
1225	N	1275	FMT	1325	N	1375	XTO	1425	XEY	1475	PMT
1226	XTO	1276	FMT	1326	XTO	1376	FMT	1426	FMT	1476	GTO
1227	YTO	1277	A	1327	E	1377	PMT	1427	FMT	1477	1
1228	FMT	1278	E	1328	α	1378	UP	1428	N	1478	5
1229	XFR	1279	α	1329	CHT	1379	XFR	1429	E	1479	3
1230	3	1280	0	1330	π	1380	5	1430	XTO	1480	7
1231	2	1281	CHT	1331	α	1381	0	1431	CHT	1481	FMT
1232	PMT	1282	L	1332	E	1382	FMT	1432	L	1482	FMT
1233	α	1283	I	1333	YTO	1383	FMT	1433	I	1483	XTO
1234	FMT	1284	F	1334	YTO	1384	YTO	1434	F	1484	α
1235	FMT	1285	XTO	1335	.	1385	1/X	1435	XTO	1485	I
1236	XTO	1286	FMT	1336	FMT	1386	N	1436	FMT	1486	N
1237	α	1287	PMT	1337	XFR	1387	CHT	1437	PMT	1487	CHT
1238	I	1288	XFR	1338	5	1388	E	1438	XEY	1488	A
1239	N	1289	2	1339	4	1389	YE	1439	A	1489	N
1240	CHT	1290	1	1340	UP	1390	XTO	1440	FMT	1490	G
1241	A	1291	X	1341	XFR	1391	α	1441	FMT	1491	L
1242	N	1292	XFR	1342	5	1392	A	1442	XTO	1492	E
1243	G	1293	2	1343	+	1393	CHT	1443	0	1493	SFL
1244	L	1294	0	1344	DN	1394	IND	1444	XTO	1494	.
1245	E	1295	+	1345	PMT	1395	XTO	1445	A	1495	3
1246	CHT	1296	XFR	1346	XFR	1396	YTO	1446	L	1496	CLR
1247	A	1297	1	1347	3	1397	.	1447	CHT	1497	A
1248	XTO	1298	4	1348	FMT	1398	FMT	1448	F	1498	N
1249	C	1299	XEY	1349	FMT	1399	PMT	1449	0	1499	D

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1500	CNT	1550	XTO								
1501	CEX	1551	CNT								
1502	0	1552	π								
1503	CNT	1553	α								
1504	YTO	1554	0								
1505	0	1555	B								
1506	α	1556	.								
1507	◊	1557	CLR								
1508	XFR	1558	J								
1509	CLX	1559	.								
1510	CLR	1560	B								
1511	XFR	1561	.								
1512	0	1562	IND								
1513	1/X	1563	CNT								
1514	CNT	1564	CNT								
1515	M	1565	7								
1516	1/X	1566	6								
1517	YTO	1567	.								
1518	XTO	1568	0								
1519	CNT	1569	0								
1520	YTO	1570	4								
1521	XTO	1571	CLR								
1522	A	1572	CLR								
1523	α	1573	CLR								
1524	XTO	1574	CLR								
1525	CLR	1575	CLR								
1526	0	1576	FMT								
1527	INT	1577	GTO								
1528	E	1578	0								
1529	α	1579	0								
1530	CNT	1580	0								
1531	A	1581	0								
1532	G	1582	END								
1533	A										
1534	I										
1535	N										
1536	FMT										
1537	K										
1538	CLX										
1539	FMT										
1540	FMT										
1541	α										
1542	E										
1543	A										
1544	D										
1545	XFR										
1546	CNT										
1547	N										
1548	E										
1549	YE										

STORAGE REGISTERS

STORAGE	
b	Temp.
a	α
000	
001	W_B
002	L_G
003	m
004	η
005	λ
006	δ
007	t
008	$\bar{c}$
009	
010	Z_B
011	Wind, fps
012	ρ_o, slug/ft^3
013	ρ, "
014	$K=q\sqrt{V_B}^{4/3}$
015	
016	
017	
018	
019	$dC_L/d\alpha$
020	C_{Do}
021	$dC_D/d\alpha^2$
022	
023	
024	
025	
026	
027	
028	
029	Aero Mom.
030	Mech. Mom.
031	Extras Mom.
032	Σ Mom.
033	u
034	Sp. Lift $s.L$
035	a_0 } X_{CB}
036	a_1 } X_{CB}
037	a_2 } X_{CB}
038	a_0 } ρ/ρ_o
039	a_1 } ρ/ρ_o

040	$y_{CB}/\bar{c}$	
041	$\sqrt{V_B}^{2/3}$	
042	$\sqrt{V_B}$	
043	$\Delta\alpha$ Trigger	$\Delta\alpha$ .1
044	Prev. $\Delta\alpha$	
045	2nd Prev. $\Delta\alpha$	
046	$\Delta\alpha$ Trigger	.01
047	Prev. $\Delta\alpha$	
048	2nd Prev $\Delta\alpha$	
049	Temp.	
050	Σ Wt. EXTRA	
051	$\Sigma Wt_E(X-X^{CP})$	
052	$\Sigma Wt_E(y-y^{CP})$	
053		
054	$X^{CP}=26.6$	
055	$y^{CP}=-31.9$	
056		
057		
058		
059		
060		
061	$X_{co}/\bar{c}$	1
062	$dX/\bar{c}/d\alpha$	
063	$X_{co}/\bar{c}$	2
064	$dX/\bar{c}/d\alpha$	
065	$X_{co}/\bar{c}$	3
066	$dX/\bar{c}/d\alpha$	
067	$X_{co}/\bar{c}$	4
068	$dX/\bar{c}/d\alpha$	
069	$X_{co}/\bar{c}$	5
070	$dX/\bar{c}/d\alpha$	
071		
072		
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3.4.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution. For a discussion of the particulars of this problem, see Section 4.

```
PROG.#76.004
TRIM,DESIGN ALT.
FAN.2 T.BALLOON
VOL.
      45000.000*
WEIGHT
        970.000*
LENGTH HULL
         83.700*
X-CONF.PT.
         26.600*
Y-CONF.PT
        -31.900*
X,Y CG-,M,N,S
         57.300*
         -2.500*
         30.700
         29.400
         31.900
IF NO EXTRA WTS
ENT.# IN X
OTHERWISE,ENTER
WT.IN Z,Y IN Y
AND X IN X
ENT.# IN X AFTER
ENTRIES COMPLETE
        250.000
        -31.900
         26.600

ALT.FT.MSL
      14000.000*
WIND,KNOTS
         25.000*
GUESS TRIM ANGLE
         10.000*

DYN.PRESS
          1.379
P
         20.758
T
          8.581
U
         32.204
```

```
MECH.MOMENT
       8694.528
AERO.MOM.
      -8718.038
EXTRAS MOM.
          0.000
SUM OF MOMENTS
        -23.510
TRIM ANGLE ATCK
          7.570
CL
          0.371
AERO LIFT
        647.052
CD
          0.147
DRAG
        255.881
X-CENTER PRES.
         47.358
GROSS LIFT
       1934.101
TOT.LIFT
       2581.153
SUM EXTRA WTS.
        250.000
TOTAL WEIGHT
       1220.000
NET LIFT
       1361.153
TOTAL FAPLE
       1384.996
ANGLE TO HORIZON
         79.353
READY NEXT PROB.

J.B.M  76.004
```

3.4.8 NOTES

A. If incorrect data is entered, do not press STOP END to restart program. For proper restart, clearing all registers, press the following:

STOP
GO TO
1
5
3
7
CONT

B. Extra weight entry, STOPS 8, can also be used to include the payload if desired. It will not affect the trim angle if located at the confluence point.

	(X)	(Y)	(Z)
Stop 8, Enter	X^{CP}	Y^{CP}	Wt_P

It will affect the net lift and hence the total force and its angle.

C. This program was written for a Family-2 Balloon Design. It was tailored for a 45,000 CF size with several constants for this size built into the program. Should any of these differ when an actual 45,000 CF balloon is flown and measurements made, the following table indicates what step/numbers in the program should be changed. The table also indicates the changes required to make a universal program for any size Family-2 balloon.

	As Written		To Modify for Continued 45,000 CF Use		To Generalize for any Size Family-2	
Step No.	Key		Key		Key	
0363	2	X of Confluence	n	Insert	4	Stop No. 4
0364	6	Point = 26.6 ft	n	Mod.	↑	
0356	.	$= X^{CP}$	.	Dist.	↑	
0366	6		n		STOP	Ent X^{CP} in X
0384	3	Y of Confluence	n	Insert	5	Stop No. 5
0385	1	Point = 31.9 ft	n	Mod.	↑	
0386	.	$= Y^{CP}$	.	Dist	↑	
0387	9		n		↑	
0388	ChgS		ChgS		STOP	Ent Y^{CP} in X

	As Written		To Modify for Continued 45,000 CU Use		To Generalize for any Size Family-2	
Step No.	Key		Key		Key	
0410	5	X of Center of	n	Insert	6	Stop No. 6
0411	7	Gravity = 57.3 ft	n	Mod.	↑	
0412	•	= X_{CG}	•	Dist.	↑	
0413	3		n		STOP	Ent X_{CG} in X
0417	2	Y of Center of	n	Insert	7	Stop No. 7
0418	•	Gravity = 2.5 ft	•	Mod.	↑	
0419	5	= Y_{CG}	n	Dist.	↑	
0420	ChgS		n(or ChgS)		STOP	Ent Y_{CG} in X

D. Conversely, several parameters left as entries might be desired as fixed inputs when only one specific 45,000 CF balloon (or other size) is being investigated. The volume, weight, and envelope length may be fixed by the following keystrokes

Step No.	Key		Step No.	Key		Step No.	Key	
0030	n	Vol of Balloon, V_B	0316	$X^{\frown}_{\smile}Y$		0332	1	
0301	n		0317	X^y		0333	PNT	
0302	n		0318	X→		0334	FMT	
0303	n		0319	4		0335	FMT	
0304	n		0320	1		0336	H	
0305	n		0321	FMT		0337	U	
0306	X→		0322	FMT		0338	L	
0307	4		0323	W		0339	L	
0308	2		0324	T		0340	FMT	
0309	PNT		0325	•		0341	n	Envelope Length, $\bar{c}$
0310	↑		0326	FMT		0342	n	
0311	2		0327	n	Wt of Balloon W_B	0343	n	
0312	↑		0328	n		0344	n	
0313	3		0329	n		0345	n	
0314	÷		0330	n		0346	n	
0315	↓		0331	X→				

If a volume other than 45,000 CF was being considered, the modifications shown in Note C must also be made.

3.5 Program 76.005 – FAMILY-2 Tethered Balloon Trim, Variable Altitude and Wind Profiles

3.5.1 GENERAL DESCRIPTION

A type of tethered balloon, called the FAMILY-2, has an aerodynamic shape and two vertical and two horizontal fins. During its development model wind-tunnel and full scale static and flight tests were made in extensive detail. References 1 and 2 provide a sufficient amount of information on a 200,000 CF system to write a trim equation with more exact constants than any other balloon now available.

Program No. 76.005 (and 76.004) were approached with the idea of providing a quick solution to trim problems as well as inputs to the tether-cable program. They were tailored for a 45,000 CF balloon which the AFGL will receive in 1976. However, they can be easily converted into a completely general program as explained in Section 3.5.8.

Program No. 76.004 is concerned with the condition where the balloon is completely filled with gas, that is, its ballonet is empty. It will be called the design condition. Program No. 76.005 was designed to accommodate both the design condition as well as other conditions at lower altitudes where the ballonet is in various stages of air inflation.

Due to the extensive measurements made with the 200,000 CF FAMILY-2 balloon by the Range Measurements Lab of the Air Force Eastern Test Range, it was possible to obtain data which allowed use of the balloon center-of-pressure. Like the neutral-point, it is defined as the point where the pitching-moment is zero. This permits the elimination of one term in the moment equation developed under Program No. 76.003 where a fixed aerodynamic center was utilized. The longitudinal variation of CP with trim angle was computed in non-dimensional form.

Since the RML balloon features a large windscreen to cover its payload and the more general balloon being considered does not have a windscreen, the differences in aerodynamic characteristics had to be obtained from wind-tunnel tests of the two designs. Since flight data differed significantly from wind-tunnel data, the delta windscreen effects were applied to the flight data to obtain the full scale aerodynamic characteristics of a FAMILY-2 balloon without windscreen.

The center of buoyancy location was non-dimensionalized from flight measurements of the RML balloon assuming that the windscreen has no effect. The vertical location is a straight line function of trim angle-of-attack. However, the longitudinal location is a function of both trim angle and ballonet fullness. For the case of an empty ballonet, a curve-fit with a correlation of 0.99 was possible. This fit is used in Program No. 76.004, the design condition.

For the general case, Program No. 76.005, a complete fit of all four measured cases (Ballonet Empty, 1/3 full, 2/3 full, and full) which is within the scope

of this computer program, was more difficult and permits larger errors than the design case. An error in the longitudinal position of the center-of-buoyancy of up to 0.3 ft in a balloon having an envelope length of 100 ft is an outer limit. Uncertainties in other balloon or atmospheric parameters could be larger sources of error. However, the effect of the center of buoyancy error can be noted where design conditions from the output from Program No. 76.004 and from the first output group from Program No. 76.005 are compared.

In Program No. 76.005 ballonet fullness is computed at each lower altitude on the assumption that the initial flight altitude entered is the design altitude where the ballonet is empty. Computations are first made for the design altitude, then proceed downward at delta-altitude increments to, and including, the surface altitude. No check on the ballonet's ability to handle the total altitude excursion is made within this program. Therefore as an initial step, Program No. 76.001 can be utilized to obtain both the no-wind buoyancy/weight balance as well as the acceptability of the altitude excursion by the ballonet.

3.5.2 DEVELOPMENT OF PROGRAM AND EQUATIONS

This case covers a specific tethered balloon type wherein:

a. the location of the aerodynamic center of pressure ($C_M = 0$) is known and can be utilized rather than an arbitrary fixed aerodynamic reference center ($C_M \neq 0$).

b. the fore and aft location of the center of pressure varies with angle of attack, α.

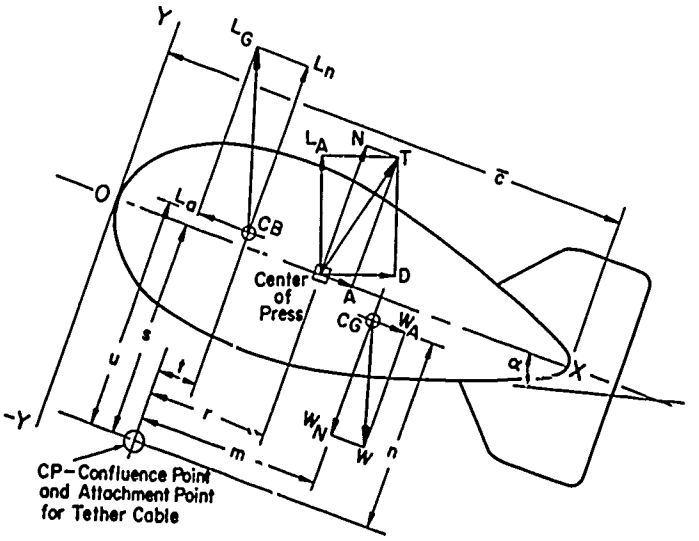
c. the location of the center of buoyancy varies with α and the "fullness" of the ballonet.

d. the balloon will be flown at the design altitude (ballonet empty) and at lower altitudes, where the ballonet fills with air as the gas volume decreases.

A. The object of the program is to determine the trim conditions of the balloon and the total force and its angle which must be resisted by the tether-cable. The tether cable is attached at the confluence point of the multiple flying lines attached to the balloon's skin. Hence at trim:

Σ Moments at Confluence Point = 0

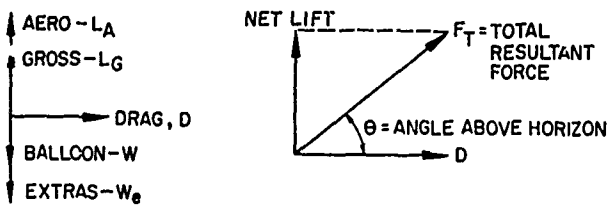
Positive moments are clockwise



The moment Eq. (10) developed for Program 76.003 in Section 3.3.2 is applicable here provided the aerodynamic pitching-moment is removed. The equation then becomes:

$$0 = mW - tL + \tan\alpha\,(mW - uL) \qquad \text{(Mech. Mom.)}$$
$$- K\,[ra\,\alpha - sb - sc\alpha^2 + \tan\alpha\,(sa\,\alpha + rb + rc\alpha^2)] \qquad \text{(Aero Mom.)}$$
$$+ \cos\alpha\,[\Sigma W_e\,(x - x^{CP}) + \tan\alpha\,\Sigma W_e\,(y - y^{CP})] \qquad \text{(Extras Mom.)}$$

B. After solving for α_{trim} the Aero Lift (L_A) and Drag, can be calculated and used with buoyancy and Mass terms to obtain total Resultant Force (F_T) and angle (θ) at the Confluence Point.



C. Use 2 constant form for density ratio (same in all programs)

$$\frac{\ln \rho/\rho_o}{Z} = a_o + a_1 a$$

where

$$a_1 = -1.7772^{-10}$$
$$a_o = -2.81361^{-5}$$

D. For 45,000 CF Ballcon, let

$X_{CG} = 57.3$ ft
$Y_{CG} = -2.5$
$X^{CP} = 26.6$
$Y^{CP} = -31.9$
$s = 31.9$
$\overline{c} = 83.7$

Built into program. See Notes to change to entry quantities or to change values

CG Location assumed unchanged with α variation. RML tests for CG were made with empty ballonet and therefore best for design condition.

E. Center of Buoyancy - All Ballonet Conditions

Hull lengh = $\overline{c}$

From Reference 1, $\frac{Y_{CB}}{\bar{c}}$ varies as a straight line between two conditions;

$\frac{Y_{CB}}{\bar{c}}$ = .00363 Ballonet Empty

$\frac{Y_{CB}}{\bar{c}}$ = .06178 Ballonet Full

$\frac{Y_{CB}}{\bar{c}} = .00363 + .05815\,\gamma$

where

γ = Ballonet Fullness Fraction

Using Reference 1 measured data, Figure E4-10, the following equation permitted a reasonable fit to that curve presented.

$$\frac{X_{CB}}{\bar{c}} = A_0 + f_0\alpha + f_1\alpha\gamma + f_2\alpha\gamma^2 + g_0\alpha^2 + g_1\alpha^2\gamma + g_2\alpha^2\gamma^2 + g_3\alpha^2\gamma^3$$

where

$A_0 = .427$	$g_0 = .00004389$
$f_0 = -.001030$	$g_1 = .00005097$
$f_1 = -.005411$	$g_2 = .0002048$
$f_2 = .004689$	$g_3 = .0001692$

F. Aero Coefficients - Flight data corrected for no windscreen by difference in wind-tunnel data with and without windscreen.

a. $C_L = .049\,\alpha$ or $dC_L/d\alpha = .049$

b. $C_D = .106 + .00071\alpha^2 = C_{D_O} + \frac{dC_D}{d\alpha^2}\alpha^2$

$C_{D_O} = .106$ = minimum drag at $\alpha = 0$

$dC_D/d\alpha^2 = .00071$

c. $\frac{Y_{CP}}{\bar{c}} = 0$

d. $\frac{X_{CP}}{\bar{c}}$ from W.T. tests w/o windscreen. A series of straight lines is used to define the variation of $X_{CP}/\bar{c}$ with α.

Region	α Base	$(\frac{X_{CP}}{c})$ Base	$\frac{d\frac{X_{CP}}{c}}{d\alpha}$	α Range
1	0	.657	.2691	0 - .55
2	.55	.805	-.4350	.55 - 1.35
3	1.35	.457	.1229	1.35 - 1.7
4	1.7	.50	.01395	1.7 - 6.0
5	6.0 26.0	.56 .634	.00370	6.0 - 26+

$$\frac{X_{CP}}{\bar{c}} = (\frac{X_{CP}}{\bar{c}}) \text{ Base} + \frac{d\frac{X_{CP}}{\bar{c}}}{d\alpha} (\alpha - \alpha_{Base})$$

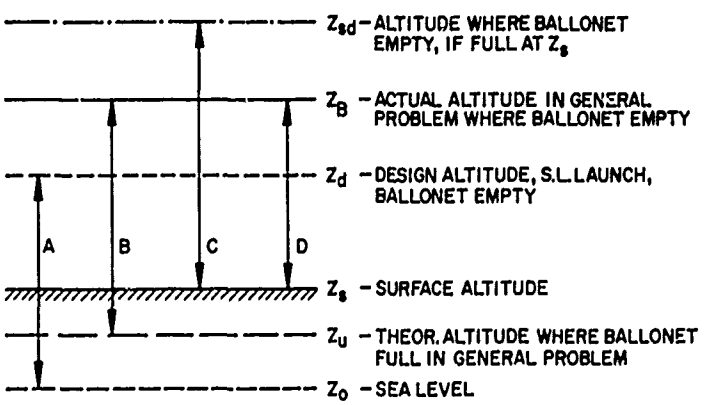
G. Ballonet Fullness Fraction

Let V_B = volume of balloon

v = Volume of Ballonet

By definition: $\frac{V_B - v}{V_B} = \frac{\rho d}{\rho o}$ which defines the maximum or design altitude which is accommodated by a ballonet of a given volume in a flight from an altitude, Z_O, where it is full of air.

(1) $v = V_B (1 - \frac{\rho d}{\rho o})$, a fixed quantity for a given balloon. In actual use, there is a greater probability that the balloon will not be flown from Z_O (Sea Level). It would probably be flown from a ground station above sea level and thus have a maximum altitude higher than if launched from sea level. More typically, the full range of flight altitude required in a project might not require the full capability of the ballonet, that is, an empty ballonet at design or maximum altitude but a partially full condition at the surface. These various flight conditions are illustrated below.



Cases A, B, and C above represent the full range of altitudes a balloon can traverse with a given fixed ballonet size, that is, the density ratio:

$$(2)\quad \frac{\rho_d}{\rho_o} = \frac{\rho_B}{\rho_{u=}} = \frac{\rho_{sd}}{\rho_s}$$

Case D is the more general case where the full capability of the ballonet may not be required, that is, the ballonet not full at Z_s.

To obtain a relationship for the variation of ballonet volume with altitude consider:

Volume of gas at Sea Level = $V_B \frac{\rho_d}{\rho_o}$, which expands to:

Volume of gas at $Z_d = V_B \frac{\rho_d}{\rho_d} = V_B$

In general, Volume of gas at $Z = V_B \frac{\rho_d}{\rho_Z} = V_B \frac{\rho_d}{\rho_o}\frac{\rho_o}{\rho_Z}$

So, Volume of Ballonet = V_B - Vol of Gas

$$(3)\quad v = V_B - V_B \frac{\rho_d}{\rho_o}\frac{\rho_o}{\rho_Z} = V_B\left(1 - \frac{\rho_d}{\rho_o}\frac{\rho_o}{\rho_Z}\right)$$

At Z = 0, $v = V_B\left(1 - \frac{\rho_d}{\rho_o}\right)$, Ballonet Full by Eq. (1) Definition

At $Z = Z_d$, $v = V_B(1-1) = 0$, Ballonet Empty

Therefore if γ = Ballonet Fullness Fraction:

$$(4)\quad \gamma = \frac{v_Z}{v_o} = \frac{V_B\left(1 - \frac{\rho_d}{\rho_o}\frac{\rho_o}{\rho_Z}\right)}{V_B\left(1 - \frac{\rho_d}{\rho_o}\right)} = \frac{1 - \frac{\rho_d}{\rho_o}\frac{\rho_o}{\rho_Z}}{1 - \rho_d/\rho_o}$$

To cover the general Case D above, the following is an equivalent definition:

$$\gamma = \frac{v_Z}{v_u} = \frac{1 - \frac{\rho_B}{\rho_u}\frac{\rho_u}{\rho_Z}}{1 - \frac{\rho_B}{\rho_u}}$$

but by the definitions in Eq. (2) above $\frac{\rho_B}{\rho_u} = \frac{\rho_d}{\rho_0}$

$$\gamma = \frac{1 - \frac{\rho_d}{\rho_o}\frac{\rho_u}{\rho_Z}}{1 - \frac{\rho_d}{\rho_o}}$$

However, since the computer program evaluates density relationships, ρ/ρ_o, the use of ρ_u/ρ_Z is undesirable. Making use of Eq. (2) relationships,

$$\frac{\rho_d}{\rho_0}\frac{\rho_u}{\rho_Z} = \frac{\rho_d}{\rho_o}\frac{\rho_o}{\rho_Z}\frac{\rho_u}{\rho_o} \text{ and } \frac{\rho_u}{\rho_o} = \frac{\rho_B}{\rho_d}$$

$$\frac{\rho_d}{\rho_o}\frac{\rho_u}{\rho_Z} = \frac{\rho_d}{\rho_o}\frac{\rho_o}{\rho_Z}\frac{\rho_B}{\rho_o}\frac{\rho_o}{\rho_d} = \frac{\rho_o}{\rho_Z}\frac{\rho_B}{\rho_o}$$

$$(5)\quad \gamma = \frac{1 - \dfrac{\rho_o}{\rho_Z}\dfrac{\rho_B}{\rho_o}}{1 - \dfrac{\rho_d}{\rho_o}}$$

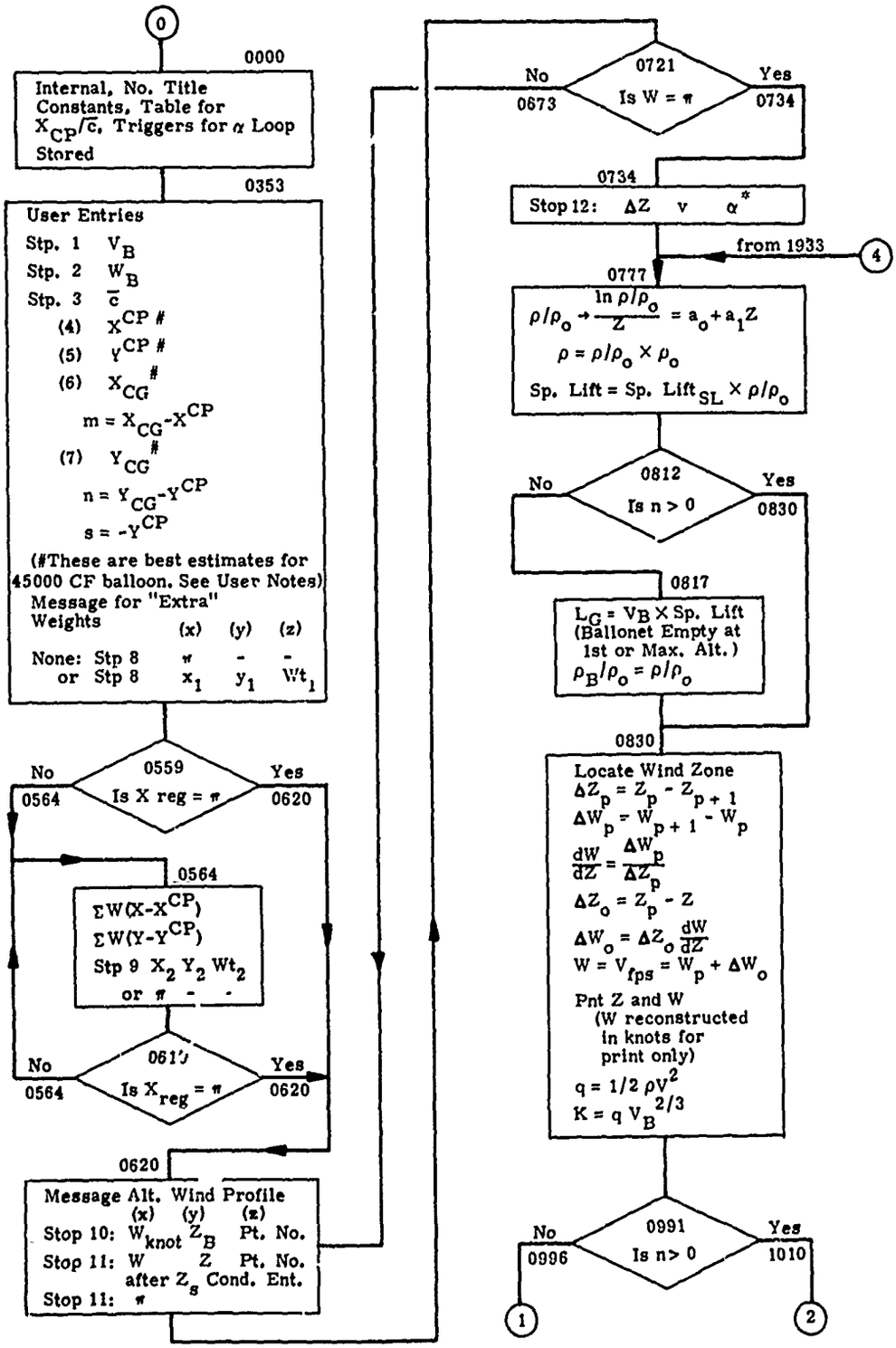
Therefore, program is designed to:

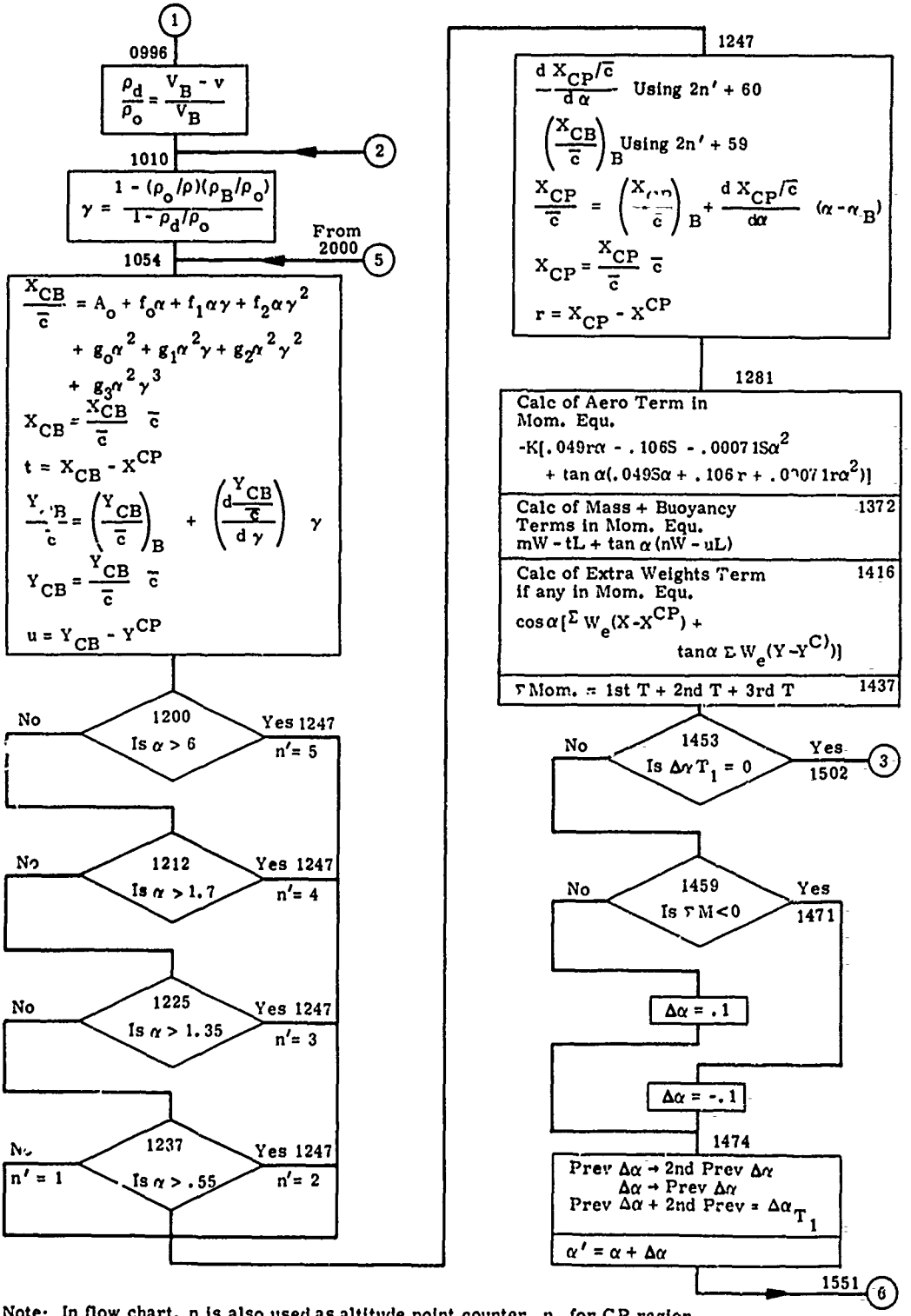
a. Obtain ρ_d/ρ_o from Eq. (1)

b. Obtain ρ_E/ρ_o from first or highest altitude calculation where ballonet is empty, $\gamma = 0$

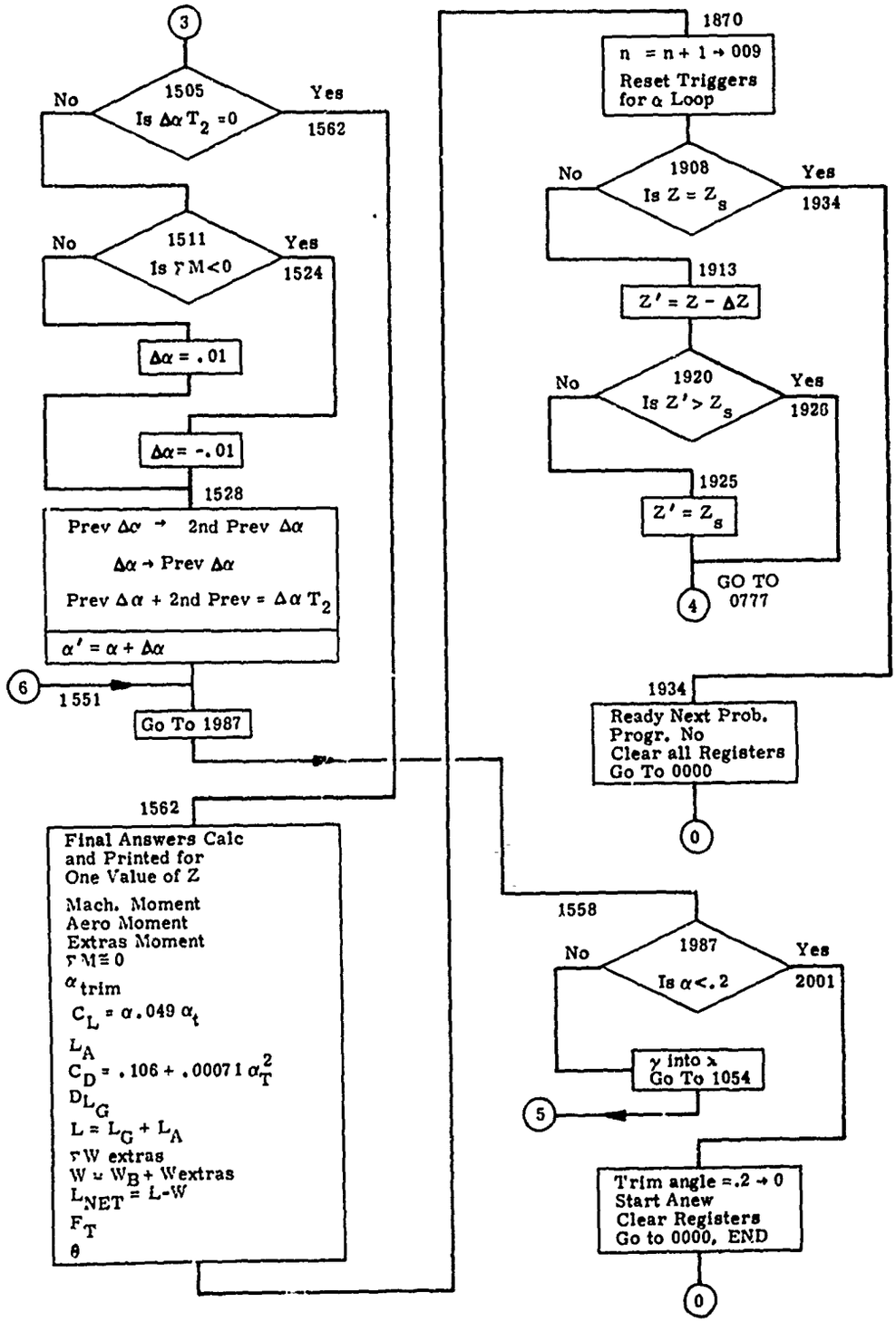
c. Obtain ρ_Z/ρ_o computed at each lower altitude.

3.5.3 FLOW CHART





Note: In flow chart, n is also used as altitude point counter, n for CP region number, and ρ for wind profile point number.


3
1505
Is $\Delta\alpha T_2 = 0$
No
Yes
1562
1511
Is $\Sigma M < 0$
No
Yes
1524
$\Delta\alpha = .01$
$\Delta\alpha = -.01$
1528
Prev $\Delta\alpha$ → 2nd Prev $\Delta\alpha$
$\Delta\alpha$ → Prev $\Delta\alpha$
Prev $\Delta\alpha$ + 2nd Prev = $\Delta\alpha T_2$
$\alpha' = \alpha + \Delta\alpha$
6
1551
Go To 1987
1562
Final Answers Calc and Printed for One Value of Z
Mach. Moment
Aero Moment
Extras Moment
$\Sigma M \equiv 0$
α_{trim}
$C_L = \alpha .049\ \alpha_t$
L_A
$C_D = .106 + .0007\ 1\ \alpha_T^2$
D_{L_G}
$L = L_G + L_A$
ΣW extras
$W = W_B$ + Wextras
$L_{NET} = L - W$
F_T
θ
1870
n = n + 1 → 009
Reset Triggers for α Loop
1908
Is $Z = Z_s$
No
Yes
1934
1913
$Z' = Z - \Delta Z$
1920
Is $Z' > Z_s$
No
Yes
1926
1925
$Z' = Z_s$
4
GO TO 0777
1934
Ready Next Prob. Progr. No
Clear all Registers
Go To 0000
0
1558
1987
Is $\alpha < .2$
No
Yes
2001
γ into α
Go To 1054
5
Trim angle = .2 → 0
Start Anew
Clear Registers
Go to 0000, END
0

3.5.4 OPERATING INSTRUCTIONS

KEY STROKES	ENTRIES			PRINTS
RUN				
END				
FIX, 2, 3, ----				(No. of desired decimal places)
CONT	(X)	(Y)	(Z)	Program No. and Title
Stop 1, Enter:	V_B	—	—	
CONT				V_B, Balloon Volume, CF
Stop 2, Enter:	W_B	—	—	
CONT				W_B, Balloon Weight, lb
Stop 3, Enter:	$\bar{c}$	—	—	$\bar{c}$, Length, Hill ft
(Stops 4, 5, 6, and 7 not in program as written. use of these for X^{CP}, Y^{CP}, X_{CG}, and Y_{CG})				See notes for optional
				Directions for "Extra" weights: Ent. π in x if none. Ent. Wt in Z, y in Y, x in X. Ent. π in X after all entries made.
Stop 8, Enter π or:	X_1	Y_1	W_1	
CONT				W_1 (if entered) Y_1 (if entered) X_1 (if entered)
(If π goes to Stop 10)				
Stop 9, Enter π or:	X_2	Y_2	W_2	
CONT				W_2 (if entered) Y_2 (if entered) X_2 (if entered)
(If π goes to Stop 10)				
				Directions for Alt-Wind Profile: Ent. π in x after surface entry. [First Entries at Stop 10 must be Pt. No. for Max Balloon Altitude (Empty Ballonet)]
Stop 10, Enter:	W	Z_B	Pt. No. = 1	
CONT				1, Pt. No. Z_B, Max Balloon Alt, ft MSL W, Wind, Knots
Stop 11, Enter:	W	Z	Pt. No.	
CONT				Pt. No. Z, Alt, ft W, Wind, Knots

(After Z_s is entered

Stop 11, Enter: π — —

CONT

Stop 12, Enter: ΔZ v α

CONT

α, Guess trim angle, Deg
v, Balloonet volume, CF
ΔZ, Desired decrements in Alt, ft

(Program begins computations)

ALT
Z, ft
WIND
W, Knots
DYN. PRES.
q, lb/ft^2
BALLOONET FULLNESS
γ

Pause in α-trim loop, step 1552, α in X reg. and Σ Moments in Y and Z as search is made for α trim where Σ Moments = 0. When found, printouts then occur as follows:

MECH. MOM.
Value of Mech. Moment, ft-lb
AERO MOM.
Value of Aero Moment, ft-lb
EXTRAS MOM.
Value of Extras Moment, ft-lb
SUM OF MOM.
ΣMoments $\cong$ 0
TRIM ANGLE ATCK
α, deg
C_L C_L
AERO LIFT
L_A, lb
CD C_D
DRAG
D, lb
GROSS BUOY. LIFT
L_G, lb
TOT. LIFT
$L = L_A + L_G$, lb
SUM "EXTRA" WTS
ΣW_{extra}, lb
TOT. WEIGHT
$W = W_B + \Sigma W_{extra}$, lb
NET LIFT
$L_N = L - W$, lb

TOTAL FORCE

$$F_T = \sqrt{L_N^2 + D^2}, \text{ lb}$$

ANGLE TO HORIZON

$$\theta = \arctan L_N/D, \text{ deg}$$

Program now brings Balloon down ΔZ in altitude, recomputes wind, q and ballonet fullness and goes through another α trim search. When a Z value less than Z-surface is reached, Z-surface is substituted and the surface conditions are the last block of computed data. Completion is indicated by following:

Ready Next Problem

J.B.W. 76-005

A new set of data can now be entered at first stop in program after repeat of Title and number.

3.5.5. SAMPLE INPUT DATA FORM

INPUT			76.002, 76.003, 76.004, and 76.005			
			76.003, 76.004, 76.005 EXTRA WEIGHT TABLE		76.003 and 76.005 WIND PROFILE*	
Balloon Volume	V_B	cu ft	W_1	lb	No. 1	1
Ballonet Volume	v	cu ft	Y_1	ft	Z_{MAX}, ft MSL	
Balloon Weight	W_B	lb	X_1	ft	Wind, knots	
Hull Length	$\bar{c}$	ft	W_2		No. 2	2
① Location of Confluence Pt.	Y^{CP}	ft	Y_2		Z_2	
	X^{CP}	ft	X_2		$Wind_2$	
① Location of Center of Gravity	Y^{CG}	ft	W_3		No. 3	3
	X^{CG}	ft	Y_3		Z_3	
② Location of Center of Buoyancy	Y^{CB}	ft	X_3		$Wind_3$	
	X^{CB}	ft	W_4		No. 4	4
③ Location of Aero Reference Center	Y^{ARC}	ft	Y_4		Z_4	
	X^{ARC}	ft	X_4		$Wind_4$	
Altitude, Max	Z_M	ft	W_5		No. 5	5
Altitude, Surf	Z_S	ft	Y_5		Z_5	
Increment of Alt	ΔZ	ft	X_5		$Wind_5$	
② $dC_L/d\alpha$	a		W_6		No. 6	6
③ C_{D_O}	b		Y_6		Z_6	
③ $dC_D/d\alpha^2$	c		X_6		$Wind_6$	
③ C_M TABLE*			W_7		No. 7	7
NO. 1	1		Y_7		Z_7	
α_1	0	deg	X_7		$Wind_7$	
C_{M1}			W_8		No. 8	8
NO. 2	2		Y_8		Z_8	
α_2		deg	X_8		$Wind_8$	
C_{M2}			W_9		No. 9	9
NO. 3	3		Y_9		Z_9	
α_3		deg	X_9		$Wind_9$	
C_{M3}			W_{10}		No. 10	10
NO. 4	4		Y_{10}		Z_{10}	
α_4		deg	X_{10}		$Wind_{10}$	
C_{M4}			W_{11}		No. 11	11
NO. 5	5		Y_{11}		Z_{11}	
α_5		deg	X_{11}		$Wind_{11}$	
C_{M5}			W_{12}		No. 12	12
NO. 6	6		Y_{12}		Z_{12}	
α_6		deg	X_{12}		$Wind_{12}$	
C_{M6}			W_{13}		No. 13	13
NO. 7	7		Y_{13}		Z_{13}	
α_7		deg	X_{13}		$Wind_{13}$	
C_{M7}						

① See Note 76.005
② Req'd for 76.002 and 76.003
③ Req'd for 76.003 only
* A minimum of two points must be used, a maximum of seven points may be used. First point must be for $\alpha = 0°$

Any number of "extra" weights may be used. One entry can be Instrument Package and Payload. If these are at Confluence Point make
$Y = Y^{CP}$
$X = X^{CP}$

*A minimum of 2 Points must be used and a maximum of 13 may be used. First must be Z_{MAX} and last must be Z_{SURF}. 76.004 requires one value of wind.

3.5.6 PROGRAM 76.005 - TRIM, FAMILY-2, VARIABLE ALT. AND WIND PROFILES

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0000	--CLR	0050	-- 7	0100	-- 5	0150	-- 8	0200	-- 0	0250	-- 7
0001	--FNT	0051	-- 7	0101	-- 4	0151	--XTO	0201	-- 2	0251	--XTO
0002	--FNT	0052	-- 7	0102	-- 1	0152	-- 0	0202	-- 0	0252	-- 0
0003	-- π	0053	-- 2	0103	-- 1	0153	-- 2	0203	-- .	0253	-- 6
0004	-- α	0054	--CHS	0104	--CHS	0154	-- 7	0204	-- 0	0254	-- 5
0005	-- 0	0055	--EEX	0105	--XTO	0155	-- 1	0205	-- 0	0255	-- .
0006	-- G	0056	-- 1	0106	-- 0	0156	-- 6	0206	-- 0	0256	-- 1
0007	-- .	0057	-- 0	0107	-- 2	0157	-- 9	0207	-- 7	0257	-- 2
0008	--GTO	0058	--CHS	0108	-- 3	0158	-- 2	0208	-- 1	0258	-- 2
0009	-- 7	0059	--XTO	0109	-- .	0159	--CHS	0209	--XTO	0259	-- 9
0010	-- 6	0060	-- 0	0110	-- 0	0160	--EEX	0210	-- 0	0260	--XTO
0011	-- .	0061	-- 3	0111	-- 0	0161	-- 7	0211	-- 2	0261	-- 0
0012	-- 0	0062	-- 9	0112	-- 4	0162	--CHS	0212	-- 1	0262	-- 6
0013	-- 0	0063	-- 2	0113	-- 6	0163	--XTO	0213	-- .	0263	-- 6
0014	-- 5	0064	-- .	0114	-- 8	0164	-- 0	0214	-- 6	0264	-- .
0015	--CLR	0065	-- 8	0115	-- 9	0165	-- 2	0215	-- 5	0265	-- 5
0016	--XTO	0066	-- 1	0116	--XTO	0166	-- 8	0216	-- 7	0266	--XTO
0017	-- α	0067	-- 3	0117	-- 0	0167	-- .	0217	--XTO	0267	-- 0
0018	-- I	0068	-- 6	0118	-- 2	0168	-- 0	0218	-- 0	0268	-- 6
0019	-- M	0069	-- 1	0119	-- 4	0169	-- 0	0219	-- 6	0269	-- 7
0020	--CLX	0070	--CHS	0120	-- 4	0170	-- 3	0220	-- 1	0270	-- .
0021	-- D	0071	--EEX	0121	-- 3	0171	-- 6	0221	-- .	0271	-- 0
0022	-- E	0072	-- 5	0122	-- 8	0172	-- 3	0222	-- 2	0272	-- 1
0023	-- C	0073	--CHS	0123	-- 9	0173	--XTO	0223	-- 6	0273	-- 3
0024	-- α	0074	--XTO	0124	--EEX	0174	-- 0	0224	-- 9	0274	-- 9
0025	-- .	0075	-- 0	0125	-- 8	0175	-- 3	0225	-- 1	0275	-- 5
0026	-- A	0076	-- 3	0126	--CHS	0176	-- 6	0226	--XTO	0276	--XTO
0027	-- L	0077	-- 8	0127	--XTO	0177	-- .	0227	-- 0	0277	-- 0
0028	--XTO	0078	-- .	0128	-- 0	0178	-- 0	0228	-- 6	0278	-- 6
0029	--YTO	0079	-- 4	0129	-- 2	0179	-- 5	0229	-- 2	0279	-- 8
0030	-- ,	0080	-- 2	0130	-- 5	0180	-- 8	0230	-- .	0280	-- .
0031	--CLR	0081	-- 7	0131	-- 5	0181	-- 1	0231	-- 8	0281	-- 5
0032	-- F	0082	--XTO	0132	-- 0	0182	-- 5	0232	-- 0	0282	-- 6
0033	-- R	0083	-- 0	0133	-- 9	0183	--XTO	0233	-- 5	0283	--XTO
0034	-- M	0084	-- 3	0134	-- 7	0184	-- 0	0234	--XTO	0284	-- 0
0035	-- .	0085	-- 5	0135	--CHS	0185	-- 3	0235	-- 0	0285	-- 6
0036	-- 2	0086	-- .	0136	--EEX	0186	-- 7	0236	-- 6	0286	-- 9
0037	--CNT	0087	-- 0	0137	-- 8	0187	-- .	0237	-- 3	0287	-- .
0038	--XTO	0088	-- 0	0138	--CHS	0188	-- 0	0238	-- .	0288	-- 0
0039	-- .	0089	-- 1	0139	--XTO	0189	-- 4	0239	-- 4	0289	-- 0
0040	-- B	0090	-- 0	0140	-- 0	0190	-- 9	0240	-- 3	0290	-- 3
0041	-- A	0091	-- 3	0141	-- 2	0191	--XTO	0241	-- 5	0291	-- 7
0042	-- L	0092	--CHS	0142	-- 6	0192	-- 0	0242	--CHS	0292	--XTO
0043	-- L	0093	--XTO	0143	-- .	0193	-- 1	0243	--XTO	0293	-- 0
0044	-- O	0094	-- 0	0144	-- 0	0194	-- 9	0244	-- 0	0294	-- 7
0045	-- O	0095	-- 2	0145	-- 0	0195	-- .	0245	-- 6	0295	-- 0
0046	-- N	0096	-- 2	0146	-- 0	0196	-- 1	0246	-- 4	0296	-- 1
0047	--FNT	0097	-- .	0147	-- 2	0197	-- 0	0247	-- .	0297	-- 1
0048	-- 1	0098	-- 0	0148	-- 0	0198	-- 6	0248	-- 4	0298	--XTO
0049	-- .	0099	-- 0	0149	-- 4	0199	--XTO	0249	-- 5	0299	-- 4

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0300	3	0350	1	0400	9	0450	XTO	0500	N	0550	FMT
0301	XTO	0351	XTO	0401	CHS	0451	α	0501	CNT	0551	8
0302	4	0352	6	0402	XTO	0452	A	0502	XFR	0552	UP
0303	5	0353	STP	0403	8	0453	CNT	0503	CLR	0553	UP
0304	XTO	0354	PRT	0404	5	0454	IND	0504	YE	0554	STP
0305	4	0355	XTO	0405	5	0455	E	0505	CNT	0555	YTO
0306	6	0356	4	0406	UP	0456	I	0506	I	0556	α
0307	XTO	0357	2	0407	5.	0457	G	0507	N	0557	XEY
0308	0	0358	UP	0408	7	0458	H	0508	CNT	0558	π
0309	4	0359	2	0409	.	0459	XTO	0509	YE	0559	X=Y
0310	8	0360	UP	0410	3	0460	YTO	0510	CLR	0560	0
0311	0	0361	3	0411	RUP	0461	CLR	0511	E	0561	6
0312	XTO	0362	DIV	0412	-	0462	E	0512	N	0562	2
0313	4	0363	DN	0413	YTO	0463	N	0513	XTO	0563	0
0314	4	0364	XEY	0414	0	0464	XTO	0514	.	0564	α
0315	XTO	0365	H	0415	0	0465	.	0515	CHS	0565	RUP
0316	4	0366	XTO	0416	3	0466	CHS	0516	CNT	0566	PRT
0317	7	0367	0	0417	2	0467	CNT	0517	I	0567	XTO
0318	XTO	0368	4	0418	.	0468	I	0518	N	0568	α
0319	5	0369	1	0419	5	0469	N	0519	CNT	0569	XTO
0320	0	0370	2	0420	CHS	0470	CNT	0520	YE	0570	+
0321	XTO	0371	UP	0421	RUP	0471	YE	0521	CNT	0571	5
0322	5	0372	UP	0422	-	0472	CLR	0522	A	0572	0
0323	1	0373	STP	0423	YTO	0473	0	0523	F	0573	DN
0324	XTO	0374	PRT	0424	0	0474	XTO	0524	XTO	0574	PRT
0325	0	0375	XTO	0425	0	0475	H	0525	E	0575	XEY
0326	5	0376	0	0426	4	0476	E	0526	α	0576	PRT
0327	2	0377	0	0427	CHS	0477	α	0527	A	0577	PRT
0328	.	0378	1	0428	XTO	0478	IND	0528	L	0578	UP
0329	0	0379	3	0429	6	0479	I	0529	L	0579	XFR
0330	6	0380	UP	0430	FMT	0480	YTO	0530	CNT	0580	5
0331	5	0381	UP	0431	FMT	0481	E	0531	IND	0581	4
0332	9	0382	STP	0432	I	0482	CLX	0532	E	0582	-
0333	8	0383	PRT	0433	F	0483	E	0533	I	0583	XFR
0334	8	0384	XTO	0434	CNT	0484	N	0534	G	0584	5
0335	XTO	0385	0	0435	XTO	0485	XTO	0535	H	0585	5
0336	0	0386	0	0436	H	0486	E	0536	XTO	0586	RUP
0337	3	0387	8	0437	E	0487	α	0537	YTO	0587	XEY
0338	4	0388	2	0438	α	0488	CLR	0538	CNT	0588	-
0339	.	0389	6	0439	E	0489	IND	0539	A	0589	α
0340	0	0390	.	0440	CNT	0490	XTO	0540	α	0590	X
0341	0	0391	6	0441	A	0491	.	0541	E	0591	YTO
0342	2	0392	XTO	0442	α	0492	I	0542	CLR	0592	+
0343	3	0393	0	0443	E	0493	N	0543	E	0593	5
0344	7	0394	5	0444	CNT	0494	CNT	0544	N	0594	2
0345	8	0395	4	0445	N	0495	XSQ	0545	XTO	0595	RUP
0346	XTO	0396	UP	0446	0	0496	CLX	0546	E	0596	X
0347	0	0397	3	0447	CLR	0497	XFR	0547	α	0597	YTO
0348	1	0398	1	0448	E	0498	CNT	0548	E	0598	+
0349	3	0399	.	0449	YE	0499	I	0549	D	0599	0

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0600	5	0650	CNT	0700	RUP	0750	YTO	0800	YTO	0850	8
0601	1	0651	YE	0701	XEY	0751	IND	0801	1	0851	6
0602	9	0652	CNT	0702	1	0752	α	0802	3	0852	4
0603	UP	0653	A	0703	.	0753	1	0803	DN	0853	1
0604	UP	0654	F	0704	6	0754	2	0804	XFR	0854	UP
0605	STP	0655	XTO	0705	8	0755	UP	0805	3	0855	b
0606	YTO	0656	E	0706	7	0756	UP	0806	4	0856	+
0607	α	0657	α	0707	9	0757	STP	0807	X	0857	YTO
0608	XEY	0658	YTO	0708	X	0758	RUP	0808	XFR	0858	b
0609	π	0659	1/X	0709	YTO	0759	PNT	0809	9	0859	GTO
0610	X=Y	0660	α	0710	IND	0760	RUP	0810	UP	0860	0
0611	0	0661	F	0711	α	0761	PNT	0811	0	0861	8
0612	6	0662	.	0712	1	0762	RUP	0812	X<Y	0862	3
0613	2	0663	E	0713	1	0763	PNT	0813	0	0863	0
0614	0	0664	H	0714	UP	0764	PNT	0814	8	0864	2
0615	GTO	0665	XTO	0715	UP	0765	YTO	0815	3	0865	RUP
0616	0	0666	α	0716	STP	0766	0	0816	0	0866	XEY
0617	5	0667	XFR	0717	YTO	0767	XTO	0817	XFR	0867	-
0618	6	0668	FMT	0718	0	0768	1	0818	4	0868	YTO
0619	4	0669	STP	0719	XEY	0769	6	0819	2	0869	α
0620	1	0670	YTO	0720	π	0770	RUP	0820	RUP	0870	XFR
0621	0	0671	1	0721	X=Y	0771	XTO	0821	X	0871	IND
0622	UP	0672	0	0722	0	0772	5	0822	YTO	0872	α
0623	UP	0673	RUP	0723	7	0773	7	0823	2	0873	XTO
0624	FMT	0674	PNT	0724	3	0774	XFR	0824	XFR	0874	5
0625	FMT	0675	RUP	0725	4	0775	1	0825	1	0875	8
0626	A	0676	PNT	0726	XFR	0776	0	0826	8	0876	RUP
0627	L	0677	RUP	0727	0	0777	UP	0827	XTO	0877	-
0628	XTO	0678	PNT	0728	XEY	0778	UP	0828	7	0878	1
0629	.	0679	PNT	0729	GTO	0779	XFR	0829	3	0879	RUP
0630	IND	0680	YTO	0730	0	0780	3	0830	b	0880	+
0631	I	0681	0	0731	6	0781	9	0831	UP	0881	YTO
0632	H	0682	XEY	0732	7	0782	X	0832	1	0882	α
0633	D	0683	2	0733	3	0783	XFR	0833	+	0883	XFR
0634	CNT	0684	RUP	0734	1	0784	3	0834	2	0884	IND
0635	π	0685	X	0735	XTO	0785	8	0835	X	0885	α
0636	α	0686	7	0736	-	0786	+	0836	7	0886	XTO
0637	0	0687	9	0737	c	0787	DN	0837	9	0887	0
0638	F	0688	+	0738	XFR	0788	X	0838	+	0888	5
0639	I	0689	YTO	0739	IND	0789	DN	0839	YTO	0889	9
0640	L	0690	α	0740	α	0790	J	0840	α	0890	2
0641	E	0691	XFR	0741	XTO	0791	XTO	0841	XFR	0891	+
0642	E	0692	0	0742	1	0792	1	0842	IND	0892	YTO
0643	H	0693	XTO	0743	5	0793	8	0843	α	0893	α
0644	XTO	0694	IND	0744	UP	0794	UP	0844	UP	0894	XFR
0645	.	0695	α	0745	2	0795	UP	0845	XFR	0895	IND
0646	CHS	0696	1	0746	XTO	0796	XFR	0846	1	0896	α
0647	CNT	0697	+	0747	+	0797	1	0847	0	0897	XEY
0648	I	0698	YTO	0748	α	0798	2	0848	X>Y	0898	XFR
0649	H	0699	α	0749	-	0799	X	0849	0	0899	5

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0900	9	0950	K	1000	UP	1050	YTO	1100	X	1150	2
0901	-	0951	N	1001	XFR	1051	.	1101	YTO	1151	2
0902	DN	0952	0	1002	0	1052	FNT	1102	+	1152	X
0903	XEY	0953	XTO	1003	-	1053	PNT	1103	5	1153	XFR
0904	DIV	0954	YTO	1004	DN	1054	UP	1104	8	1154	5
0905	XFR	0955	FNT	1005	XEY	1055	XSQ	1105	XFR	1155	8
0906	5	0956	PNT	1006	DIV	1056	X	1106	2	1156	+
0907	8	0957	XFR	1007	YTO	1057	XFR	1107	5	1157	XFR
0908	UP	0958	1	1008	7	1058	5	1108	RUP	1158	3
0909	XFR	0959	3	1009	4	1059	7	1109	X	1159	5
0910	1	0960	XEY	1010	XFR	1060	XSQ	1110	YTO	1160	+
0911	0	0961	XSQ	1011	1	1061	X	1111	+	1161	XFR
0912	-	0962	X	1012	8	1062	XFR	1112	5	1162	8
0913	DN	0963	2	1013	1/X	1063	2	1113	8	1163	X
0914	X	0964	DIV	1014	UP	1064	8	1114	XFR	1164	XFR
0915	XFR	0965	XFR	1015	XFR	1065	X	1115	5	1165	.5
0916	5	0966	4	1016	7	1066	YTO	1116	7	1166	4
0917	9	0967	1	1017	3	1067	5	1117	UP	1167	-
0918	+	0968	XEY	1018	X	1068	8	1118	XFR	1168	YTO
0919	1	0969	X	1019	1	1069	XFR	1119	6	1169	7
0920	.	0970	YTO	1020	XEY	1070	6	1120	0	1170	XFR
0921	6	0971	1	1021	-	1071	0	1121	X	1171	6
0922	8	0972	4	1022	1	1072	XSQ	1122	X	1172	0
0923	7	0973	FNT	1023	UP	1073	UP	1123	UP	1173	UP
0924	8	0974	FNT	1024	XFR	1074	XFR	1124	XFR	1174	XFR
0925	YTO	0975	D	1025	7	1075	5	1125	2	1175	3
0926	1	0976	XFR	1026	4	1076	7	1126	4	1176	7
0927	1	0977	N	1027	-	1077	XSQ	1127	RUP	1177	X
0928	UP	0978	.	1028	DN	1078	X	1128	X	1178	XFR
0929	DN	0979	π	1029	DIV	1079	XFR	1129	YTO	1179	3
0930	DIV	0980	a	1030	YTO	1080	2	1130	+	1180	6
0931	XFR	0981	E	1031	6	1081	7	1131	5	1181	+
0932	1	0982	YTO	1032	0	1082	X	1132	8	1182	XFR
0933	0	0983	YTO	1033	DN	1083	YTO	1133	XFR	1183	8
0934	FNT	0984	.	1034	FNT	1084	+	1134	2	1184	X
0935	FNT	0985	FNT	1035	FNT	1085	5	1135	3	1185	XFR
0936	A	0986	PNT	1036	B	1086	8	1136	XEY	1186	5
0937	L	0987	XFR	1037	A	1087	XFR	1137	XFR	1187	5
0938	XTO	0988	9	1038	L	1088	5	1138	5	1188	-
0939	.	0989	UP	1039	L	1089	7	1139	7	1189	YTO
0940	FNT	0990	0	1040	0	1090	XSQ	1140	X	1190	0
0941	PNT	0991	X<Y	1041	N	1091	UP	1141	RUP	1191	3
0942	DN	0992	1	1042	E	1092	UP	1142	RUP	1192	3
0943	FNT	0993	0	1043	XTO	1093	XFR	1143	X	1193	5
0944	FNT	0994	1	1044	CHT	1094	6	1144	YTO	1194	UP
0945	IND	0995	0	1045	F	1095	0	1145	+	1195	XFR
0946	I	0996	XFR	1046	1/X	1096	X	1146	5	1196	5
0947	N	0997	4	1047	L	1097	XFR	1147	8	1197	7
0948	D	0998	2	1048	L	1098	2	1148	DN	1198	UP
0949	CLX	0999	UP	1049	N	1099	6	1149	XFR	1199	6

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1200	X<Y	1250	X	1300	X	1350	6	1400	3	1450	XFR
1201	1	1251	6	1301	DN	1351	XEY	1401	X	1451	4
1202	2	1252	0	1302	XEY	1352	XFR	1402	DN	1452	3
1203	4	1253	+	1303	+	1353	2	1403	-	1453	X=Y
1204	7	1254	YTO	1304	XFR	1354	0	1404	XFR	1454	1
1205	1	1255	α	1305	5	1355	X	1405	5	1455	5
1206	.	1256	XFR	1306	UP	1356	XFR	1406	7	1456	0
1207	7	1257	IND	1307	XFR	1357	5	1407	0	1457	2
1208	RUP	1258	α	1308	2	1358	9	1408	X	1458	DN
1209	4	1259	RUP	1309	0	1359	XEY	1409	XFR	1459	X>Y
1210	RUP	1260	X	1310	X	1360	-	1410	5	1460	1
1211	RUP	1261	1	1311	DN	1361	DN	1411	8	1461	4
1212	X<Y	1262	RUP	1312	+	1362	XEY	1412	+	1462	7
1213	1	1263	XEY	1313	XFR	1363	+	1413	YTO	1463	1
1214	2	1264	-	1314	5	1364	XFR	1414	3	1464	.
1215	4	1265	YTO	1315	7	1365	1	1415	0	1465	1
1216	7	1266	α	1316	0	1366	4	1416	XFR	1466	GTO
1217	1	1267	XFR	1317	X	1367	CHS	1417	5	1467	1
1218	.	1268	IND	1318	XFR	1368	X	1418	2	1468	4
1219	3	1269	α	1319	5	1369	YTO	1419	UP	1469	7
1220	5	1270	RUP	1320	7	1370	2	1420	XFR	1470	4
1221	RUP	1271	+	1321	UP	1371	9	1421	5	1471	.
1222	3	1272	XFR	1322	XFR	1372	XFR	1422	7	1472	1
1223	RUP	1273	8	1323	5	1373	1	1423	0	1473	CHS
1224	RUP	1274	X	1324	X	1374	UP	1424	X	1474	UP
1225	X<Y	1275	XFR	1325	XFR	1375	XFR	1425	XFR	1475	XFR
1226	1	1276	5	1326	1	1376	3	1426	5	1476	4
1227	2	1277	4	1327	9	1377	X	1427	1	1477	4
1228	4	1278	-	1328	X	1378	XFR	1428	+	1478	XTO
1229	7	1279	YTO	1329	YTO	1379	2	1429	XFR	1479	4
1230	.	1280	5	1330	5	1380	UP	1430	5	1480	5
1231	5	1281	XFR	1331	9	1381	XFR	1431	7	1481	YTO
1232	5	1282	5	1332	DN	1382	7	1432	N	1482	4
1233	RUP	1283	7	1333	XFR	1383	X	1433	X	1483	4
1234	2	1284	XSQ	1334	5	1384	DN	1434	YTO	1484	XEY
1235	RUP	1285	X	1335	7	1385	-	1435	3	1485	+
1236	RUP	1286	XFR	1336	XSQ	1386	YTO	1436	1	1486	YTO
1237	X<Y	1287	2	1337	UP	1387	5	1437	XFR	1487	4
1238	1	1288	1	1338	XFR	1388	8	1438	3	1488	3
1239	2	1289	X	1339	6	1389	XFR	1439	0	1489	XEY
1240	4	1290	XFR	1340	X	1390	1	1440	+	1490	XFR
1241	7	1291	6	1341	XFR	1391	UP	1441	XFR	1491	5
1242	1	1292	UP	1342	2	1392	XFR	1442	2	1492	7
1243	RUP	1293	XFR	1343	1	1393	4	1443	9	1493	+
1244	RUP	1294	1	1344	X	1394	X	1444	+	1494	YTO
1245	XEY	1295	9	1345	YTO	1395	XFR	1445	0	1495	5
1246	0	1296	X	1346	-	1396	2	1446	YTO	1496	7
1247	-	1297	XFR	1347	5	1397	UP	1447	3	1497	GTO
1248	2	1298	5	1348	9	1398	XFR	1448	2	1498	1
1249	RUP	1299	7	1349	XFR	1399	3	1449	UP	1499	5

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1500	5	1550	7	1600	PNT	1650	M	1700	8	1750	PNT
1501	1	1551	PSE	1601	+	1651	CNT	1701	XFR	1751	UP
1502	XFR	1552	.	1602	XFR	1652	A	1702	2	1752	XFR
1503	4	1553	2	1603	3	1653	N	1703	1	1753	5
1504	6	1554	GTO	1604	1	1654	G	1704	X	1754	8
1505	X=Y	1555	1	1605	+	1655	L	1705	XFR	1755	+
1506	1	1556	9	1606	FMT	1656	E.	1706	2	1756	DN
1507	5	1557	8	1607	FMT	1657	CNT	1707	0	1757	FMT
1508	6	1558	7	1608	E	1658	A	1708	+	1758	FMT
1509	2	1559	GTO	1609	YE	1659	XTO	1709	XFR	1759	XTO
1510	DN	1560	1	1610	XTO	1660	C	1710	1	1760	0
1511	X>Y	1561	0	1611	a	1661	K	1711	4	1761	XTO
1512	1	1562	5	1612	A	1662	FMT	1712	XEY	1762	.
1513	5	1563	4	1613	YTO	1663	PNT	1713	X	1763	L
1514	2	1564	FMT	1614	CNT	1664	FMT	1714	FMT	1764	I
1515	4	1565	FMT	1615	M	1665	FMT	1715	FMT	1765	F
1516	.	1566	M	1616	O	1666	C	1716	C	1766	XTO
1517	0	1567	E	1617	M	1667	L	1717	D	1767	FMT
1518	1	1568	C	1618	E	1668	FMT	1718	FMT	1768	PNT
1519	GTO	1569	H	1619	N	1669	UP	1719	PNT	1769	YTO
1520	1	1570	CNT	1620	XTO	1670	XSQ	1720	DN	1770	5
1521	5	1571	M	1621	FMT	1671	XEY	1721	FMT	1771	8
1522	2	1572	O	1622	PNT	1672	UP	1722	FMT	1772	UP
1523	8	1573	M	1623	DN	1673	XFR	1723	D	1773	XFR
1524	.	1574	E	1624	FMT	1674	1	1724	a	1774	1
1525	0	1575	N	1625	FMT	1675	9	1725	A	1775	UP
1526	1	1576	XTO	1626	YTO	1676	X	1726	G	1776	XFR
1527	CHS	1577	FMT	1627	1/X	1677	DN	1727	FMT	1777	5
1528	UP	1578	XFR	1628	M	1678	PNT	1728	PNT	1778	0
1529	XFR	1579	3	1629	CNT	1679	UP	1729	UP	1779	+
1530	4	1580	0	1630	O	1680	XFR	1730	XFR	1780	FMT
1531	7	1581	PNT	1631	F	1681	1	1731	2	1781	FMT
1532	XTO	1582	UP	1632	CNT	1682	4	1732	FMT	1782	YTO
1533	4	1583	XFR	1633	M	1683	X	1733	FMT	1783	1/X
1534	8	1584	2	1634	O	1684	DN	1734	G	1784	M
1535	YTO	1585	9	1635	M	1685	FMT	1735	a	1785	X>Y
1536	4	1586	FMT	1636	E	1686	FMT	1736	O	1786	E
1537	7	1587	FMT	1637	N	1687	A	1737	YTO	1787	YE
1538	XEY	1588	A	1638	XTO	1688	E	1738	YTO	1788	XTO
1539	+	1589	E	1639	YTO	1689	a	1739	CNT	1789	a
1540	YTO	1590	a	1640	FMT	1690	O	1740	B	1790	A
1541	4	1591	O	1641	PNT	1691	CNT	1741	1/X	1791	X>Y
1542	6	1592	CNT	1642	XFR	1692	L	1742	O	1792	IND
1543	XEY	1593	M	1643	5	1693	I	1743	XFR	1793	XTO
1544	XFR	1594	O	1644	7	1694	F	1744	.	1794	YTO
1545	5	1595	M	1645	FMT	1695	XTO	1745	L	1795	
1546	7	1596	E	1646	FMT	1696	FMT	1746	I	1796	FMT
1547	+	1597	N	1647	XTO	1697	PNT	1747	F	1797	PNT
1548	YTO	1598	XTO	1648	a.	1698	XTO	1748	XTO	1798	DN
1549	5	1599	FMT	1649	I	1699	5	1749	FMT	1799	FMT

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1800	FMT	1850	A	1900	7	1950	B	2000	4		
1801	XTO	1851	N	1901	XFR	1951	.	2001	FMT		
1802	0	1852	G	1902	1	1952	FMT	2002	FMT		
1803	XTO	1853	L	1903	9	1953	K	2003	XTO		
1804	.	1854	E	1904	UP	1954	CLX	2004	α		
1805	IND	1855	CNT	1905	XFR	1955	0	2005	I		
1806	E	1856	XTO	1906	1	1956	XTO	2006	M		
1807	I	1857	0	1907	5	1957	α	2007	CNT		
1808	G	1858	CNT	1908	X=Y	1958	XTO	2008	A		
1809	H	1859	H	1909	1	1959	b	2009	N		
1810	XTO	1860	0	1910	9	1960	FMT	2010	G		
1811	FMT	1861	α	1911	3	1961	FMT	2011	L		
1812	PNT	1862	I	1912	4	1962	J	2012	E		
1813	-	1863	XSQ	1913	XEY	1963	.	2013	SFL		
1814	XFR	1864	0	1914	UP	1964	B	2014	.		
1815	5	1865	N	1915	XFR	1965	.	2015	2		
1816	8	1866	FMT	1916	1	1966	IND	2016	EEX		
1817	XEY	1867	PNT	1917	6	1967	.	2017	0		
1818	FMT	1868	PNT	1918	-	1968	CNT	2018	CLR		
1819	FMT	1869	PNT	1919	DN	1969	CNT	2019	YTO		
1820	N	1870	XFR	1920	X>Y	1970	7	2020	XTO		
1821	E	1871	9	1921	1	1971	6	2021	A		
1822	XTO	1872	UP	1922	9	1972	.	2022	α		
1823	CNT	1873	1	1923	2	1973	0	2023	XTO		
1824	L	1874	+	1924	6	1974	0	2024	CNT		
1825	I	1875	YTO	1925	DN	1975	5	2025	A		
1826	F	1876	0	1926	XTO	1976	CLR	2026	N		
1827	XTO	1877	0	1927	1	1977	CLR	2027	E		
1828	FMT	1878	9	1928	0	1978	CLR	2028	IND		
1829	PNT	1879	1	1929	GTO	1979	CLR	2029	FMT		
1830	XEY	1880	1	1930	0	1980	CLR	2030	K		
1831	A	1881	XTO	1931	7	1981	FMT	2031	CLX		
1832	FMT	1882	4	1932	7	1982	GTO	2032	GTO		
1833	FMT	1883	3	1933	7	1983	0	2033	0		
1834	XTO	1884	XTO	1934	FMT	1984	0	2034	END		
1835	0	1885	4	1935	FMT	1985	0				
1836	XTO	1886	5	1936	α	1986	0.				
1837	A	1887	XTO	1937	E	1987	X>Y				
1838	L	1888	4	1938	A	1988	2				
1839	CNT	1889	6	1939	D	1989	0				
1840	F	1890	XTO	1940	XFR	1990	0				
1841	0	1891	0	1941	CNT	1991	1				
1842	α	1892	4	1942	N	1992	DN				
1843	C	1893	8	1943	E	1993	XFR				
1844	E	1894	0	1944	YE	1994	6				
1845	FMT	1895	XTO	1945	XTO	1995	0				
1846	PNT	1896	4	1946	CNT	1996	GTO				
1847	XEY	1897	4	1947	π	1997	1				
1848	FMT	1898	XTO	1948	α	1998	0				
1849	FMT	1899	4	1949	0	1999	5				

STORAGE REGISTERS

STORAGE	
b	P Counter
a	IND, USE
000	r
001	W_B
002	L_α
003	m
004	n
005	λ
006	δ
007	ℓ
008	$\bar{c}$
009	n Counter
010	Z
011	Wind, fps
012	ρ_o, slug/ft^3
013	ρ "
014	$K = q_r V_B^{2/3}$
015	Z_S
016	ΔZ
017	
018	ρ/ρ_o
019	$dC_L/d\alpha$
020	C_{D_o} (=k)
021	$dC_D/d\alpha^{(n=1)}$
022	f_o
023	f_1
024	f_2
025	g_o
026	g_1
027	g_2
028	g_3
029	Aero Mom.
030	Mech Mom
031	Extras Mom
032	Σ Mom.
033	μ
034	Sp. Lift s_L
035	A_o
036	$y_{cp}/\bar{c}$ $\delta=0$
037	$y_{cp}/\bar{c}$ Slope
038	a_o } ρ/ρ_o
039	a_1 } $/_{10}$

040		
041	$V_B^{2/3}$	
042	V_B	$\Delta\alpha$
043	$\Delta\alpha$ Trigger	.1
044	Prev. $\Delta\alpha$	
045	2nd Prev. $\Delta\alpha$	
046	$\Delta\alpha$ Trigger	.01
047	Prev. $\Delta\alpha$	
048	2nd Prev $\Delta\alpha$	
049		
050	Σ Wt$_{EXTRA}$	
051	Σ Wt$_B$ $(x-x^{cp})$	
052	Σ Wts $(y-y^{cp})$	
053		
054	$X^{cp}=26.6$	
055	$Y^{cp}=-3i.9$	
056		
057	α	
058	Temp.	
059	Temp.	
060	γ.	
061	$x_{cp}/\bar{c}$ } 1	
062	$dx/\bar{c}/d\alpha$ }	
063	$x_{cp}/\bar{c}$ } 2	
064	$dx/\bar{c}/d\alpha$ }	
065	$x_{cp}/\bar{c}$ } 3	
066	$dx/\bar{c}/d\alpha$ }	
067	$x_{cp}/\bar{c}$ } 4	
068	$dx/\bar{c}/d\alpha$ }	
069	$x_{cp}/\bar{c}$ } 5	
070	$dx/\bar{c}/d\alpha$ }	
071		
072		
073	ρ_B/ρ_o	
074	ρ_d/ρ_o	
075		
076		
077		
078		
079		

080		
081	Z_1	
082	W_1	
083	Z_2	
084	W_2	
085	Z_3	
086	W_3	
087	Z_4	E
088	W_4	V
089	Z_5	I
090	W_5	F
091	Z_6	O
092	W_6	R
093	Z_7	P
094	W_7	
095	Z_8	D
096	W_8	N
097	Z_9	I
098	W_9	W
099	Z_{10}	-
100	W_{10}	.
101	Z_{11}	T
102	W_{11}	L
103	Z_{12}	A
104	W_{12}	
105	Z_{13}	
106	W_{13}	
107	$+1/Z_{FACT.}$	
108		

3.5.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution. For a discussion of the particulars of this problem, see Section 4.

```
PROG.#76.005
TRIM;DECR.ALTS.
FAM.2 T.BALLOON
      45000.000*
        970.000*
         83.700*
IF THERE ARE NO
EXTRA WEIGHTS
ENT.# IN X
OTHERWISE,ENTER
WT.IN Z,Y IN Y
X IN X
ENT.# IN X AFTER
ALL WEIGHTS ARE
ENTERED
        250.000
        -31.900
         26.600

ALT.WIND PROFILE
ENT.# IN X AFTER
SURF.ENTRY
          1.000
      14000.000
         25.000

          2.000
      13000.000
         25.000

          3.000
      10000.000
         60.000

          4.000
       8000.000
        -15.000

          5.000
       5000.000
        -30.000

          6.000
       4000.000
        -20.000

         12.000
      13522.000
       1000.000

ALT.
      14000.000
WIND,KNOTS
         25.000
DYN.PRESS.
          1.379
BALLONET FULLNS.
          0.000
MECH MOMENT
       8512.252
AERO MOMENT
      -8537.371
EXTRAS MOMENT
          0.000
SUM OF MOMENTS
        -25.118
TRIM ANGLE ATCK
          7.490
CL
          0.367
AERO LIFT
        640.213
CD
          0.146
DRAG
        254.388
GROSS BUOY.LIFT
       1934.099
TOT.LIFT
       2574.312
SUM"EXTRA"WTS.
        250.000
TOT.WEIGHT
       1220.000
NET LIFT
       1354.312
TOTAL FORCE
       1377.997
ANGLE TO HORIZON
         79.362


ALT.
      13000.000
WIND,KNOTS
         25.000
DYN.PRESS.
          1.425
BALLONET FULLNS.
          0.108

MECH MOMENT
       9013.180
AERO MOMENT
      -9009.932
EXTRAS MOMENT
          0.000
SUM OF MOMENTS
          3.247
TRIM ANGLE ATCK
          7.570
CL
          0.371
AERO LIFT
        668.716
CD
          0.147
DRAG
        264.448
GROSS BUOY.LIFT
       1934.099
TOT.LIFT
       2602.815
SUM"EXTRA"WTS.
        250.000
TOT.WEIGHT
       1220.000
NET LIFT
       1382.815
TOTAL FORCE
       1407.875
ANGLE TO HORIZON
         79.174


ALT.
      12000.000
WIND,KNOTS
         36.667
DYN.PRESS.
          3.167
BALLONET FULLNS.
          0.211
```

```
ALT.
      10000.000
WIND,KNOTS
         60.000
DYN.PRESS.
          9.041
BALLONET FULLNS.
          0.405
MECH MOMENT
      10787.353
AERO MOMENT
     -10834.080
EXTRAS MOMENT
          0.000
SUM. OF MOMENTS
        -46.727
TRIM ANGLE ATCK
          4.480
CL
          0.220
AERO LIFT
       2510.905
CD
          0.120
DRAG
       1375.439
GROSS BUOY.LIFT
       1934.099
TOT.LIFT
       4445.004
SUM"EXTRA"WTS.
        250.000
TOT.WEIGHT
       1220.000
NET LIFT
       3225.004
TOTAL FORCE
       3506.004
ANGLE TO HORIZON
         66.902
```

```
ALT.
       5000.000
WIND,KNOTS
        -30.000
DYN.PRESS.
          2.637
BALLONET FULLNS.
          0.822
MECH MOMENT
       9743.951
AERO MOMENT
      -9759.784
EXTRAS MOMENT
          0.000
SUM OF MOMENTS
        -15.833
TRIM ANGLE ATCK
          5.930
CL
          0.291
AERO LIFT
        969.242
CD
          0.131
DRAG
        436.862
GROSS BUOY.LIFT
       1934.099
TOT.LIFT
       2903.342
SUM'EXTRA"WTS.
        250.000
TOT.WEIGHT
       1220.000
NET LIFT
       1683.342
TOTAL FORCE
       1739.105
ANGLE TO HORIZON
         75.452
```

```
ALT.
       4000.000
WIND,KNOTS
        -20.000
DYN.PRESS.
          1.207
BALLONET FULLNS.
          0.895
MECH MOMENT
       8492.403
AERO MOMENT
      -8472.253
EXTRAS MOMENT
          0.000
SUM OF MOMENTS
         20.149
TRIM ANGLE ATCK
          7.990
CL
          0.392
AERO LIFT
        597.938
CD
          0.151
DRAG
        231.115
GROSS BUOY.LIFT
       1934.099
TOT.LIFT
       2532.037
SUM"EXTRA"WTS.
        250.000
TOT.WEIGHT
       1220.000
NET LIFT
       1312.037
TOTAL FORCE
       1332.237
ANGLE TO HORIZON
         80.010


READY NEXT PROB.
J.B.M.  76.005
```

3.5.8 NOTES

A. If incorrect data is entered, do not press STOP END to restart program. For a proper restart, clearing all registers, press the following:

STOP
GO TO
1
9
3
4
CONT

B. Extra Weight entry, STOPS 8, 9

The payload weight can be included here if desired. It will not affect the trim angle if located at the confluence point:

	(X)	(Y)	(Z)
STOP 8 (or 9):	X^{CP}	Y^{CP}	Wt_P

It will affect the net lift and hence the total force and its angle.

C. Altitude-Wind entries STOPS 10, 11

1. First wind entry, STOP 10, must be Point No. 1 in (Z), starting Max altitude (Ballonet empty) in Y, and the wind at that altitude in X.
2. Up to 12 more Alt-Wind Points may be entered (STOPS 11) to define the wind profile from max altitude to the surface.
3. The last entry must be the surface altitude and surface wind.
4. A "π" is then entered to cause the program to continue on to STOP 12.

D. This program was written for a Family-2 Balloon Design. It was tailored for a 45,000 CF size with several constants for this size built into the program. Should any of these differ when an actual 45,000 CF balloon is flown and measurements made, the following table indicates what step numbers in the program should be changed. The table also indicates the changes required to make a universal program for any size Family-2 balloon.

	As Written		To Modify for Continued 45,000 CF Use		To Generalize for Any Size Family-2 Balloon	
Step No.	Key		Key		Key	
0388	2	X of Confluence	n	Insert	4	Stop No. 4
0389	6	Point = 26.6 ft	n	Mod.	↑	
0390	•	$= X^{CP}$	•	Dist.	STOP PNT	Ent X^{CP} in X
0391	6		n			
0397	3	Y of Confluence	n	Insert	5	Stop No. 5
0398	1	Point = 31.9 ft	n	Mod.	↑	
0399	•	$= Y^{CP}$	•	Dist.	↑	
0400	9		n		STOP PNT	Ent Y^{CP} in X
0401	Chg S		Chg S			
0407	5	X of Center of	n	Insert	6	Stop No. 6
0408	7	Gravity = 57.3 ft	n	Mod.	↑	
0409	•	$= X_{CG}$	•	Dist.	STOP PNT	Ent X_{CG} in X
0410	3		n			
0417	2	Y of Center of	n	Insert	7	Stop No. 7
0418	•	Gravity = 2.5 ft	n	Mod.	↑	
0419	5	$= Y_{CG}$	n	Dist.	STOP PNT	Ent Y_{CG} in X
0420	Chg S		Chg S			

E. Conversely, several parameters left as entries might be desired as fixed inputs when only one specific 45,000 CF balloon (or other size) is being investigated. The volume, weight, and envelope length may be made fixed by the following key strokes:

Step No.	Key		Step No.	Key		Step No.	Key	
0353	n	Vol of Balloon	0363	2		0373	1	
0354	n		0364	↑		0374	n	Wt of Balloon
0355	n		0365	3		0375	n	
0356	n		0366	÷		0376	n	
0357	n		0367	↓		0377	n	
0358	n		0368	$x \overset{\frown}{\smile} y$		0378	X→	
0359	X→		0369	X^Y		0379	1	
0360	4		0370	X→		0380	CNT	
0361	2		0371	0		0381	n	$\overline{c}$
0362	↑		0372	4		0382	n	
						0383	n	
						0384	n	
						0385	n	
						0386	X→	
						0387	8	

The ballonet volume, v, is incorporated by the following changes:

Step No.	Key		Step No.	Key	
0753	n	Vol. of Balloon	0763	STOP	Entry α in Y, ΔZ in X
0754	n		0764	$X \overset{\frown}{\smile} Y$	
0755	n		0765	PNT	
0756	n		0766	X→	
0757	n		0767	5	
0758	X→		0768	7	
0759	0		0769	Y→	
0760	CNT		0770	1	
0761	1		0771	6	
0762	2		0772	$X \overset{\frown}{\smile} Y$	
			0773	PNT	

If a volume other than 45,000 CF was being considered, the modifications shown in Note D must also be made.

3.6 Program No. 76.006 — Tether Cable, 2-Dimensional Case, Variable Wind Profile, Optional Internal Variable Drag Coefficient

3.6.1 GENERAL DESCRIPTION

In the flight of a tethered-balloon one is typically concerned about the ability of the balloon (a) to lift the weight of the cable, (b) to retain a reasonable magnitude of cable tension at the ground, (c) to keep the cable tension at the top within a safe limit, and (d) to keep the balloon within a reasonable definition of the word "overhead" under varying conditions of altitude and wind.

All of the forces introduced by the balloon can be summed up into one force and its angle. This total force, F_T, and the angle θ, can be computed by Program No. 76.003, 76.004, or 76.005. These two parameters are then treated as inputs to this cable Program No. 76.006.

The basic forces acting on the cable, in addition to the total force, F_T, acting at the top of the cable, are the aerodynamic drag and the cable weight. The weight is easily specified.

The drag is more difficult since it is a variable function of atmospheric density, wind velocity, and cable diameter. In addition, since the program was intended for use to altitudes up to 65,000 ft, the effect of Reynold's Number on drag coefficient could not be ignored. Accordingly, an option was permitted in the operation of the program to permit the user to either specify a cylinder, C_D, or to allow the program to compute a C_D. The former is held constant for all conditions while the latter varies with altitude-wind-velocity-diameter, per Section 3.6.2.

In concept, the cable is broken into rigid elements of a specified length, K, and the forces acting on this length evaluated to obtain a magnitude and angle which the next lower element must align with and provide equal restraint. Thereby, a series of outputs is possible at each of many points proceeding downwards from the balloon to the surface. The cable's space, position, angle, tension, and length are shown as outputs.

During the downward progression of calculations, the cable tension, T, and angle, θ, are monitored for the condition of zero tension or horizontal cable. Under such conditions, the balloon has not provided sufficient lifting force for the size and weight of cable involved and the cable is said to be unable to reach the surface. For a given balloon and cable, a lower flight altitude is indicated. If such an event occurs at the surface, the cable is lying on the ground without tension. Hauling in some cable would bring the balloon to a lower altitude and lift the cable off the ground.

For a complete evaluation, the behavior of the tether cable during its ascent or descent and at its maximum altitude should be examined. Use of Program No. 76.003 or 76.005 to provide solutions for balloon F_T and θ for maximum and

intermediate altitudes is suggested. Each of these solutions using the appropriate altitude and wind as the starting values in Program No. 76.006 will provide the complete analysis. It should be cautioned that this program as well as the others in this report provide answers for static conditions and do not attempt to consider the dynamics of balloon, cable, or system motion.

3.6.2 DEVELOPMENT OF PROGRAM AND EQUATIONS

This tether cable program will consider the 2-dimensional case only where the winds, cable, balloon and ground winch all lie in the plane of this paper. A negative wind may be used indicating flow from right to left in the diagram below.

A. The objective of the program is, starting at the top of the tether cable where it is attached to the Confluence Point, to evaluate its tension, angle, space position, etc. moving downward to the earth's surface. Consider the cable as a series of rigid cylindrical elements of length, K, attached by freely pivoting connectors. Consider the wind to be constant over length, K.

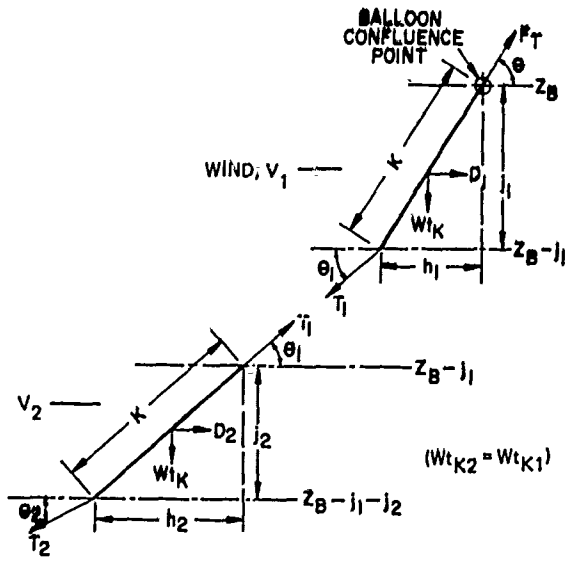
Assume no moments are produced on short element K.

Σ Forces in Horiz. Dir on 1st Element

(1) $F_T \cos\theta + D_1 = T_1 \cos\theta_1$

Σ Forces in Vert. Dir. on 1st Element

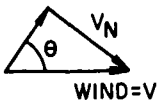
(2) $F_T \sin\theta = W_1 + T_1 \sin\theta_1$



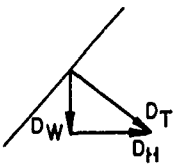
In considering drag due to wind, one method would require a table of cylinder C_D values vs pitch angles. Since C_D is also affected by R (Reynolds No), such a double variable table would be cumbersome. Instead a pitch angle of 0° will be assumed and a wind component flow concept similar to wing-sweep will be utilized. This breaks the wind into a component normal to the cylinder as the drag producer and assumes that the other component parallel to the cylinder produces a negligible

skin friction. (Note: this may be improper at supercritical values of R but is better than neglecting pitch or assuming that C_D is a constant, a difficulty of other more simple programs.)

Therefore



$V_N = V \sin\theta$



$D_H = D_T \sin\theta$

$D_W = D_T \cos\theta$

(3) $D_T = C_D qA = C_D A \frac{\rho}{2} V_N^2 = C_D A \rho/2 \, V^2 (\sin\theta)^2$

(4) $D_H = C_D A \ \rho/2 \, V^2 (\sin\theta)^3 = C_D qA (\sin\theta)^3$

(5) $D_W = C_D A \rho/2 \ (\sin\theta)^2 \cos\theta = C_D qA (\sin\theta)^2 \cos\theta$

However, the use of V_N will be required in calc. of $R_n = \frac{\rho V_N d}{\mu}$ and $q_N = \frac{\rho}{2} V_N^2$

(6) $D_T = C_D A \rho/2 \, V_N^2 = C_D A \, q_N$

(7) $D_H = C_D A \rho/2 \, V_N^2 \sin\theta = C_D A \, q_N \sin\theta$

(8) $D_W = C_D A \rho/2 \, V_N^2 \cos\theta = C_D A \, q_N \cos\theta$

Eq. (1) → (9) $F_T \cos\theta + D_{H1} = T_1 \cos\theta_1$

Eq. (2) → (10) $F_T \sin\theta = W_1 + D_{W1} + T_1 \sin\theta_1$

(11) $T_1 = \frac{F_T \cos\theta + D_{H1}}{\cos\theta_1}$

(12) $\frac{F_T \cos\theta + D_{H1}}{\cos\theta} \sin\theta_1 = F_T \sin\theta - W_1 - D_{W1}$

(13) $\tan\theta_1 = \frac{F_T \sin\theta - W_1 - D_{W1}}{F_T \cos\theta + D_{H1}}$

(14) $\theta_1 = \arctan \frac{F_T \sin\theta - (W_1 + D_{W1})}{F_T \cos\theta + D_{H1}}$ ← Angle of next lower element

(15) $T_1 = \frac{F_T \cos\theta + D_{H1}}{\cos\theta_1}$ ← Tension at top of next lower element

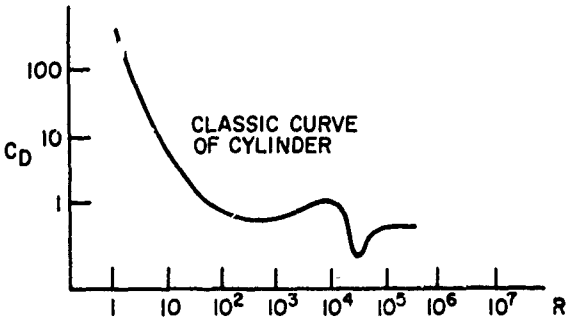
NOTE: Before obtaining values of θ_1 and T_1, the space position of the bottom end of the element is determined by:

Vert. Displ: (15) $j_1 = K \sin \theta$

Hor. Displ: (16) $h_1 = K \cos \theta$

Program proceeds on down, one K element at a time, until the sum of the $j \cong Z - Z_s$.

B. Reynolds No. vs C_D $\quad R = \dfrac{\rho V_N \text{ diam.}}{\mu}$



(17a) For $R < 1$, assumed Stokes condition: $C_D = (10.9/R)/(.87 - \text{Log } R)$
To incorporate conditions where $R > 1$ into program, series of straight lines on a semi-log plot were used as approximations. At R_{cr} area used roughness cond. $k/d = 0.009 (\frac{\text{height rough}}{\text{diam.}})$, Reference 3.

(17b) $R > 1$ $C_D = C_{D \text{ Base Point}} + K_R (\text{Log } R - \text{Log } R_{\text{Base Point}})$. This is obtained by working from low end of R towards larger values, and taking slopes of C_D-R moving left to right on plot.

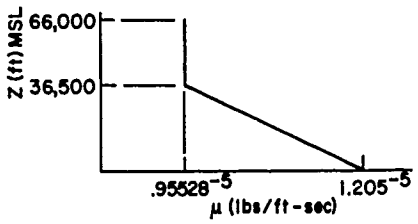
Under Condition B, ($R > 1$), the following constants are included in program storage for C_D solution.

Region		R_{Base}	$C_{D_{Base}}$	K_R
n_{CD}	$R < 9$	1	12.5	-10
n_{CD}	$R < 900$	9	2.18	-1
n_{CD}	$R < 4500$	900	.98	0
n_{CD}	$R < 9000$	4500	.98	.7308
n_{CD}	$R < 40,000$	9000	1.2	0
n_{CD}	$R < 50,000$	40,000	1.2	-4.54
n_{CD}	$R < 250,000$	50,000	.76	.3434
n_{CD}	$R > 250,000$	25,000	1.0	0

3. Hoerner, S.F. (1958) Fluid Dynamic Drag, Publ. by author.

C. Coefficient of Viscosity, μ, for $R = \frac{\rho V_N d}{\mu}$

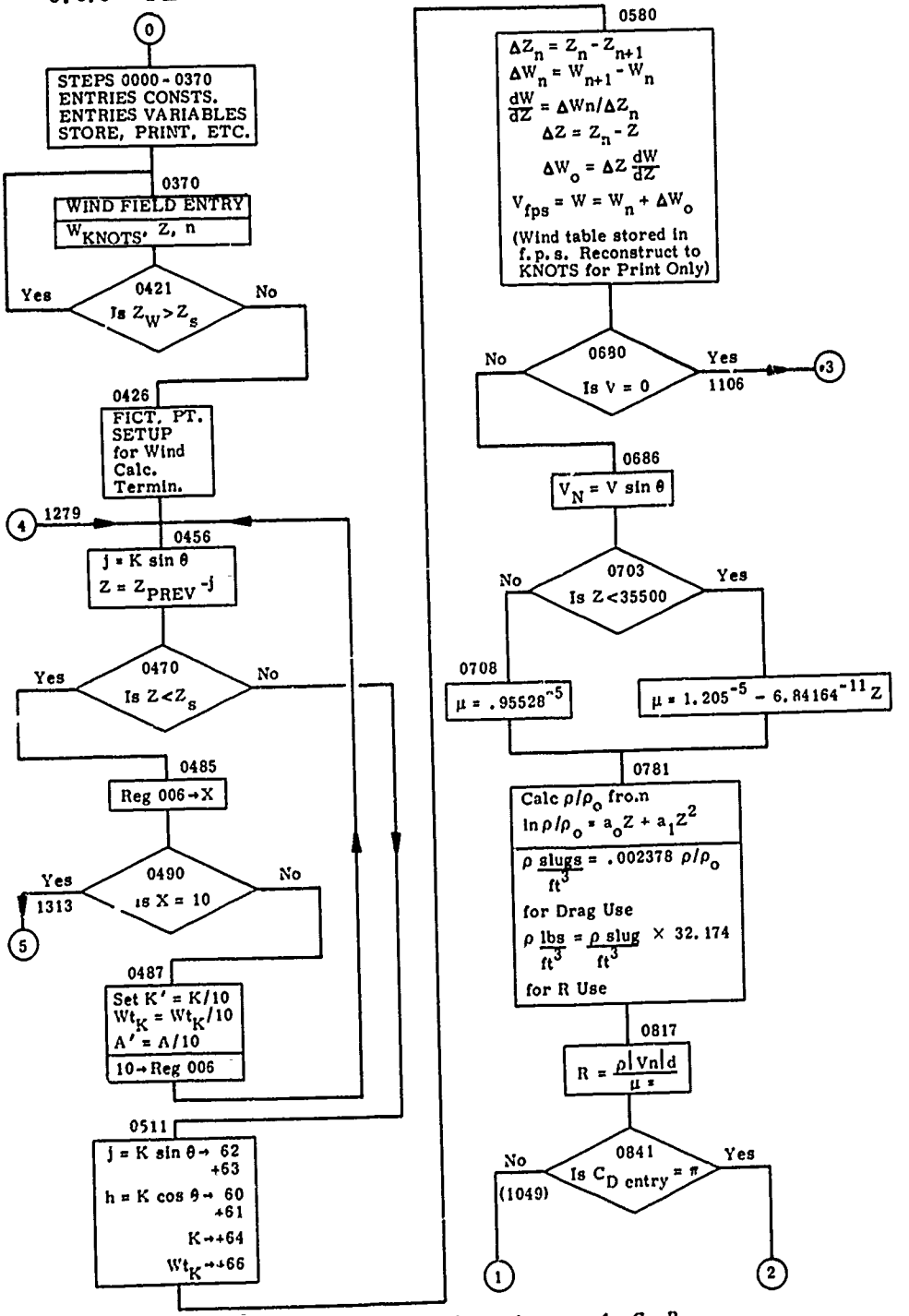
The 1962 Std. Atm. values of μ plotted shows that, within accuracies needed in this C_D useage, 2 straight lines are sufficient to define the variation of μ with altitude.



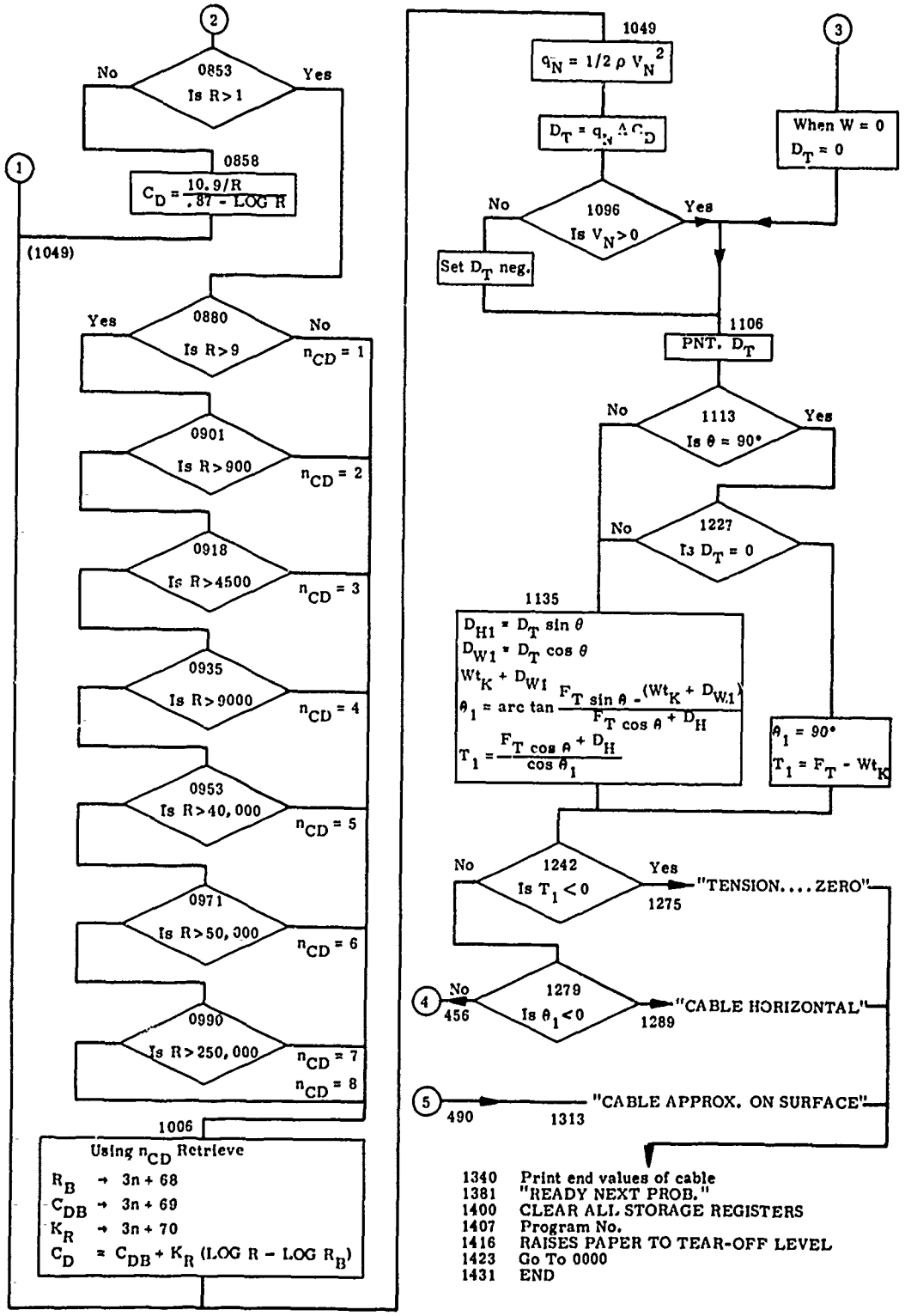
(18a) From Z = 0 to 36,500: $\mu = 1.205^{-5} - 6.84164^{-11}\ Z$,

(18b) From Z = 36,500 to 66,000: $\mu = .95528^{-5}$.

3.6.3 FLOW CHART



Note: In flow chart, n is used for wind profile point number, n_{CD} for C_D-R region number.



1340 Print end values of cable
1381 "READY NEXT PROB."
1400 CLEAR ALL STORAGE REGISTERS
1407 Program No.
1416 RAISES PAPER TO TEAR-OFF LEVEL
1423 Go To 0000
1431 END

3.6.4 OPERATING INSTRUCTIONS

KEY STROKES	ENTRIES			
RUN				
END				
FIX, 2,3,----				(No. of decimal places desired)
CONT	(X)	(Y)	(Z)	
Stop 1-1-1, Enter:	π or C_D*	Z_{Surf}, (ft, MSL)	$Z_{Balloon}$, (ft, MSL)	
	*Enter π to use built-in cylinder C_D variation or Enter C_D value which will be used throughout program.			
CONT				
Stop 2-2-2, Enter:	0 or K* (Element Length)	Wt/1000 ft(lb) (cable)	Diam. (in.) (cable)	
	*Enter 0 to set $K = \frac{Z_B - Z_S}{100}$ or Enter K in ft			
CONT				
Stop 3-3-3, Enter:	θ (deg.) (Angle to Horiz.)	F_T (lb) (Balloon tot. Force)	———	
CONT				
Stop 4-4-4, Enter:	Wind (Knots)	Z (ft) (First Entry Z Balloon)	Wind Entry Number First Entry #1)	
CONT				
Stop 4-4-4, Enter:	Wind	Z	Wind Entry Number	
	Until, last set of entries must be for Z = Z surface			
CONT				

The above entries will be printed out in groups as they are entered as follows:

Z_B	Balloon Altitude, ft MSL
Z_S	Surface Altitude, ft MSL
π or C_D	π to indicate internal use of variable C_D C_D to use as constant C_D
Diam.	Diameter of cable, in.
Wt/1000	Weight of 1000 ft of cable, lb
K	Element length, ft either K entered or $K = \frac{Z_B - Z_S}{100}$

F_T	Total balloon force, lb
θ	Angle of F_T to horizon, det

"Enter Wind Field"

1	First wind entry No.
Z_B	Altitude, (balloon), ft MSL
W	Wind, (at balloon), knots
2	Second Entry
Z	Alt
W	Wind
3	Third Entry
Z	Alt
W	Wind
-	
-	
-	
-	
-	
#	Last Entry No. (Max. 11 Sets of Entries)
Z_S	Altitude - (surface)
W	Wind (at surface)

A. The following parameters are then printed for each K element downward to surface. NOTE: To avoid print of any or all of these replace "PRINT" with "CONT" at associated program step numbers.

STEP NO.		
479	Z	Altitude, ft MSL of element bottom
530	j	Vert. Dist., top to bottom of element, ft
534	Σj	Total Vert. Dist., balloon to bottom of element
547	h	Horizontal Dist., top to bottom of element, ft
551	Σh	Total Horiz. Dist., balloon to bottom of element
561	ΣK	Total element (cable) lengths, ft
565	ΣWt_K	Total element (cable) weights, lb
675	W	Wind at bottom of element, knots, assumed acting over length of element
834	R	Reynolds number
1050	C_D	Drag Coefficient
1083	q	Dynamic pressure, lb/ft^2
1106	D_T	Total Element drag, lb
1147	D_H	Horiz Component of Drag, lb

1160	D_W	Vert. Component of Drag, lb
1194 1211	θ_1	Angle of next element, deg
1202-3 1273-4	T_1	Tension, top of next element, lb (bottom of this elem.)

B. Ending of Program:

When cable reaches near surface (<K), prints "CABLE APPROX. AT SURFACE"		If $T_1 < 0$, prints "TENSION IS ZERO"	If $\theta_1 < 0_1$ prints "CABLE HORIZONTAL"
Z	Altitude, ft (surf)	(where $T_1 \cong 0$)	(where $\theta \cong 0$)
θ_1	Angle at winch, deg	"	~0
T_1	Tension at winch	~0	(where $\theta_1 \cong 0$)
Σj	Vert. Dist., ft ($Z_B - Z_S$)	(where $T_1 \cong 0$)	"
Σh	Horiz. Dist., ft (ball. - winch)	"	"
ΣK	Cable Length, ft	"	"
ΣWt_K	Cable Weight, lb	"	"
ΣD_W	Tot. Vert. Comp. of Drag, lbs.	"	"
$\Sigma D_W + \Sigma Wt$	Sum Vertical Forces, lbs.	"	"
ΣD_H	Tot. Hor. Comp. of Drag, lb	"	"

3.6.5 SAMPLE INPUT DATA FORM

INPUT			76.006	
Altitude, Max. Starting,	Z_B		ft, MSL	
Altitude, Surface	Z_S		ft, MSL	
Cable Diameter			in.	
Cable Weight/1000 ft			lb	
Total Force	F_T		lb	From Output of 76.003, 4, or 5
Angle of F_T	θ		deg	
WIND PROFILE				
Must use minimum of 2 points. No. 1 always Z_B. Last point always Z_S. Max. No. of points: 11.	No. 1 Z Wind	1	ft, MSL knots	
	No. 2 Z Wind	2		
	No. 3 Z Wind	3		
	No. 4 Z Wind	4		
	No. 5 Z Wind	5		
	No. 6 Z Wind	6		
	No. 7 Z Wind	7		
	No. 8 Z Wind	8		
	No. 9 Z Wind	9		
	No. 10 Z Wind	10		
	No. 11 Z Wind	11		

3.6.6 PROGRAM 76.006 - TETHER CABLE, 2-DIMENSIONAL

STEP	KEY.	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0000	--CLP	0050	-- 7	0100	-- 1	0150	-- 1	0200	-- 0	0250	-- 1
0001	--FNT	0051	-- 7	0101	-- 2	0151	-- 0	0201	-- 0	0251	-- UP
0002	--FNT	0052	-- 1	0102	-- .	0152	--XTO	0202	--XTO	0252	-- UP
0003	-- ↑	0053	-- 6	0103	-- 5	0153	-- 7	0203	-- 0	0253	--STP
0004	-- a	0054	-- 7	0104	--XTO	0154	-- 9	0204	-- 8	0254	--RUP
0005	-- O	0055	--CHS	0105	-- 0	0155	--XTO	0205	-- 6	0255	--PNT
0006	-- G	0056	--EEX	0106	-- 7	0156	-- 8	0206	-- 4	0256	--XTO
0007	-- a	0057	-- 1	0107	-- 2	0157	-- 5	0207	-- .	0257	-- 3
0008	-- A	0058	-- 0	0108	-- 1	0158	--XTO	0208	-- 5	0258	--RUP
0009	-- M	0059	--CHS	0109	-- 0	0159	-- 0	0209	-- 4	0259	--PNT
0010	--CNT	0060	--XTO	0110	--CHS	0160	-- 9	0210	--CHS	0260	--XTO
0011	--GTO	0061	-- 0	0111	--XTO	0161	-- 4	0211	--XTO	0261	-- 4
0012	-- 7	0062	-- 3	0112	-- 0	0162	-- 4	0212	-- 0	0262	--RUP
0013	-- 6	0063	-- 9	0113	-- 7	0163	-- 5	0213	-- 8	0263	--PNT
0014	-- .	0064	-- 2	0114	-- 3	0164	-- 0	0214	-- 8	0264	--XTO
0015	-- 0	0065	-- .	0115	-- 9	0165	-- 0	0215	-- 5	0265	-- 0
0016	-- 0	0066	-- 8	0116	--XTO	0166	--XTO	0216	-- 0	0266	-- 7
0017	-- 6	0067	-- 1	0117	-- 0	0167	-- 0	0217	-- 0	0267	-- 0
0018	--CLR	0068	-- 3	0118	-- 7	0168	-- 8	0218	-- 0	0268	-- 2
0019	-- 2	0069	-- 6	0119	-- .	0169	-- 0	0219	-- 0	0269	-- UP
0020	-- -	0070	-- 0	0120	-- 2	0170	-- .	0220	--XTO	0270	-- UP
0021	--CNT	0071	-- 6	0121	-- .	0171	-- 7	0221	-- 0	0271	--STP
0022	-- D	0072	--CHS	0122	-- 9	0172	-- 3	0222	-- 8	0272	--RUP
0023	-- I	0073	--EEX	0123	-- 8	0173	-- 0	0223	-- 9	0273	--PNT
0024	-- M	0074	-- 5	0124	--XTO	0174	-- 8	0224	-- .	0274	--RUP
0025	-- E	0075	--CHS	0125	-- 0	0175	--XTO	0225	-- 7	0275	--PNT
0026	-- N	0076	--XTO	0126	-- 7	0176	-- 0	0226	-- 6	0276	--XTO
0027	--YTO	0077	-- 0	0127	-- 5	0177	-- 8	0227	--XTO	0277	-- 0
0028	-- I	0078	-- 3	0128	-- 1	0178	-- 2	0228	-- 0	0278	-- 0
0029	-- O	0079	-- 8	0129	--CHS	0179	-- 9	0229	-- 9	0279	-- 7
0030	-- N	0080	-- 1	0130	--XTO	0180	-- 0	0230	-- 0	0280	-- 1
0031	-- A	0081	-- .	0131	-- 0	0181	-- 0	0231	-- .	0281	-- 2
0032	-- L	0082	-- 6	0132	-- 7	0182	-- 0	0232	-- 3	0282	--DIV
0033	--CLR	0083	-- 8	0133	-- 6	0183	--XTO	0233	-- 4	0283	--YTO
0034	--XTO	0084	-- 7	0134	-- 9	0184	-- 0	0234	-- 3	0284	-- 9
0035	-- E	0085	-- 8	0135	-- 0	0185	-- 8	0235	-- 4	0285	-- DN
0036	--XTO	0086	--XTO	0136	-- 0	0186	-- 3	0236	--XTO	0286	-- 0
0037	-- H	0087	-- 0	0137	--XTO	0187	-- 1	0237	-- 0	0287	--X=Y
0038	-- E	0088	-- 3	0138	-- 0	0188	-- .	0238	-- 9	0288	-- 0
0039	-- a	0089	-- 7	0139	-- 7	0189	-- 2	0239	-- 1	0289	-- 3
0040	--CNT	0090	-- 1	0140	-- 7	0190	--XTO	0240	-- 2	0290	-- 9
0041	-- C	0091	--XTO	0141	-- .	0191	-- 8	0241	-- 5	0291	-- 7
0042	-- A	0092	-- 6	0142	-- 9	0192	-- 4	0242	-- 0	0292	--GTO
0043	-- B	0093	--XTO	0143	-- 8	0193	--XTO	0243	-- 0	0293	-- 0
0044	-- L	0094	-- 7	0144	--XTO	0194	-- 0	0244	-- 0	0294	-- 3
0045	-- E	0095	-- 1	0145	-- 7	0195	-- 8	0245	-- 0	0295	-- 0
0046	--FNT	0096	--XTO	0146	-- 8	0196	-- 7	0246	--XTO	0296	-- 9
0047	-- 1	0097	-- 0	0147	--XTO	0197	-- 4	0247	-- 0	0297	--XFR
0048	-- .	0098	-- 9	0148	-- 0	0198	-- 0	0248	-- 9	0298	-- 3
0049	-- 7	0099	-- 3	0149	-- 8	0199	-- 0	0249	-- 2	0299	-- UP

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0300	--XFR	0350	--XTO	0400	--YTO	0450	--XTO	0500	--XTO	0550	-- 1
0301	-- 4	0351	-- 4	0401	-- α	0451	-- +	0501	--DIV	0551	--PNT
0302	-- -	0352	-- 1	0402	--RUP	0452	-- α	0502	-- 7	0552	--XFR
0303	-- 1	0353	--FNT	0403	--XEY	0453	--YTO	0503	--XTO	0553	-- 7
0304	-- 0	0354	--FNT	0404	--XFR	0454	--IND	0504	--DIV	0554	--XTO
0305	-- 0	0355	-- E	0405	-- 3	0455	-- α	0505	-- 8	0555	-- +
0306	--	0356	-- N	0406	-- 7	0456	--XFR	0506	--GTO	0556	-- 6
0307	-- 0	0357	--XTO	0407	-- X	0457	-- 2	0507	-- 0	0557	-- 6
0308	--DIV	0358	--	0408	--YTO	0458	-- M	0508	-- 4	0558	--XFR
0309	-- DN	0359	--IND	0409	--IND	0459	-- UP	0509	-- 5	0559	-- 6
0310	--PNT	0360	-- I	0410	-- α	0460	--XFR	0510	-- 6	0560	-- 4
0311	-- UP	0361	-- N	0411	-- 1	0461	-- 5	0511	--XFR	0561	--PNT
0312	-- 1	0362	-- D	0412	--XTO	0462	-- X	0512	-- 2	0562	--XFR
0313	-- 0	0363	--CNT	0413	-- -	0463	--XFR	0513	-- M	0563	-- 6
0314	-- 0	0364	-- F	0414	-- α	0464	-- 4	0514	-- UP	0564	-- 6
0315	-- 0	0365	-- I	0415	--XFR	0465	-- !	0515	--XFR	0565	--PNT
0316	-- UP	0366	-- E	0416	--IND	0466	--XEY	0516	-- 5	0566	--CNT
0317	--XFR	0367	-- L	0417	-- α	0467	-- -	0517	-- X	0567	--CNT
0318	-- 7	0368	-- D	0418	-- UP	0468	--XFR	0518	--YTO	0568	--CNT
0319	--XEY	0369	--FNT	0419	--XFR	0469	-- 4	0519	-- 6	0569	--CNT
0320	--DIV	0370	-- 4	0420	-- 4	0470	--X>Y	0520	-- 2	0570	--CNT
0321	-- DN	0371	-- UP	0421	--X<Y	0471	-- 0	0521	--YTO	0571	--CNT
0322	-- X	0372	-- UP	0422	-- 0	0472	-- 4	0522	-- +	0572	--CNT
0323	--YTO	0373	--STP	0423	-- 3	0473	-- 8	0523	-- 6	0573	--CNT
0324	-- 7	0374	--RUP	0424	-- 7	0474	-- 5	0524	-- 3	0574	--CNT
0325	--XFR	0375	--PNT	0425	-- 0	0475	--YTO	0525	--XTO	0575	--CNT
0326	-- 9	0376	--RUP	0426	-- UP	0476	-- 4	0526	-- +	0576	--CNT
0327	--RUP	0377	--PNT	0427	-- 2	0477	-- 1	0527	-- 6	0577	--CNT
0328	-- X	0378	--RUP	0428	--XTO	0478	-- DN	0528	-- 4	0578	--CNT
0329	--XTO	0379	--PNT	0429	-- +	0479	--PNT	0529	--XEY	0579	--CNT
0330	-- 5	0380	--PNT	0430	-- α	0480	--GTO	0530	--PNT	0580	-- 6
0331	--YTO	0381	--YTO	0431	--XFR	0481	-- 0	0531	--XFR	0581	-- UP
0332	-- 0	0382	-- 3	0432	-- 5	0482	-- 5	0532	-- 6	0582	-- 1
0333	-- 0	0383	-- 5	0433	-- UP	0483	-- 1	0533	-- 3	0583	-- +
0334	-- 8	0384	--XEY	0434	-- 2	0484	-- 1	0534	--PNT	0584	-- 2
0335	-- 3	0385	-- 2	0435	-- X	0485	--XFR	0535	--XFR	0585	-- X
0336	-- UP	0386	--RUP	0436	-- DN	0486	-- 6	0536	-- 2	0586	-- 9
0337	-- UP	0387	-- X	0437	-- -	0487	-- UP	0537	-- M	0587	-- +
0338	--STP	0388	-- 9	0438	--YTO	0488	-- 1	0538	-- X	0588	--YTO
0339	--YTO	0389	-- +	0439	--IND	0489	-- 0	0539	--YTO	0589	-- α
0340	-- 1	0390	--YTO	0440	-- α	0490	--X=Y	0540	-- 6	0590	--XFR
0341	--XEY	0391	-- α	0441	-- 1	0491	-- 1	0541	-- 0	0591	--IND
0342	--PNT	0392	--XFR	0442	--XTO	0492	-- 3	0542	--YTO	0592	-- α
0343	--YTO	0393	-- 3	0443	-- -	0493	-- 1	0543	-- +	0593	-- UP
0344	-- 2	0394	-- 5	0444	-- α	0494	-- 3	0544	-- 6	0594	--XFR
0345	--XEY	0395	--XTO	0445	--XFR	0495	--XTO	0545	-- 1	0595	-- 4
0346	--PNT	0396	--IND	0446	--IND	0496	-- 6	0546	-- DN	0596	-- 1
0347	--PNT	0397	-- α	0447	-- α	0497	--XTO	0547	--PNT	0597	--X>Y
0348	--XFR	0398	-- 1	0448	-- UP	0498	--DIV	0548	--XFR	0598	- 0
0349	-- 3	0399	-- +	0449	-- 2	0499	-- 5	0549	-- 6	0599	-- 6

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0600	1	0650	-	0700	5	0750	CNT	0800	3	0850	9
0601	3	0651	DN	0701	9	0751	CNT	0801	7	0851	1
0602	1	0652	XEY	0702	0	0752	CNT	0802	8	0852	RUP
0603	UP	0653	DIV	0703	X>Y	0753	CNT	0803	0	0853	X>Y
0604	b	0654	XFR	0704	0	0754	CNT	0804	X	0854	0
0605	+	0655	3	0705	7	0755	CNT	0805	YTO	0855	8
0606	YTO	0656	5	0706	2	0756	CNT	0806	0	0856	8
0607	b	0657	UP	0707	5	0757	CNT	0807	4	0857	0
0608	GTO	0658	XFR	0708	.	0758	CNT	0808	2	0858	UP
0609	0	0659	4	0709	9	0759	CNT	0809	3	0859	1
0610	5	0660	1	0710	5	0760	CNT	0810	2	0860	0
0611	8	0661	-	0711	5	0761	CNT	0811	.	0861	.
0612	0	0662	DN	0712	2	0762	CNT	0812	1	0862	9
0613	2	0663	X	0713	8	0763	CNT	0813	7	0863	XEY
0614	RUP	0664	XFR	0714	EEX	0764	CNT	0814	4	0864	DIV
0615	XEY	0665	3	0715	5	0765	CNT	0815	0	0865	K
0616	-	0666	6	0716	CHS	0766	CNT	0816	X	0866	4
0617	YTO	0667	+	0717	XTO	0767	CNT	0817	XFR	0867	UP
0618	a	0668	UP	0718	4	0768	CNT	0818	4	0868	.
0619	XFR	0669	DN	0719	3	0769	CNT	0819	3	0869	8
0620	IND	0670	XFR	0720	GTO	0770	CNT	0820	DIV	0870	7
0621	a	0671	3	0721	0	0771	CNT	0821	XFR	0871	XEY
0622	RUP	0672	7	0722	7	0772	CNT	0822	9	0872	-
0623	YTO	0673	DIV	0723	8	0773	CNT	0823	X	0873	DN
0624	3	0674	DN	0724	1	0774	CNT	0824	XFR	0874	DIV
0625	5	0675	PNT	0725	6	0775	CNT	0825	5	0875	GTO
0626	-	0676	YTO	0726	.	0776	CNT	0826	1	0876	1
0627	1	0677	0	0727	8	0777	CNT	0827	XEY	0877	0
0628	RUP	0678	4	0728	4	0778	CNT	0828	G	0878	4
0629	+	0679	6	0729	1	0779	CNT	0829	X	0879	9
0630	YTO	0680	0	0730	6	0780	CNT	0830	YTO	0880	UP
0631	a	0681	X=Y	0731	4	0781	DN	0831	4	0881	0
0632	XFR	0682	1	0732	EEX	0782	DN	0832	8	0882	0
0633	IND	0683	1	0733	1	0783	XFR	0833	DN	0883	9
0634	a	0684	0	0734	1	0784	3	0834	PNT	0884	X<Y
0635	XTO	0685	6	0735	CHS	0785	9	0835	UP	0885	0
0636	0	0686	XFR	0736	X	0786	X	0836	XFR	0886	8
0637	3	0687	2	0737	1	3787	XFR	0837	7	0887	9
0638	6	0688	M	0738	.	0788	3	0838	0	0888	7
0639	2	0689	X	0739	2	0789	8	0839	UP	0889	1
0640	+	0690	YTO	0740	0	0790	+	0840	π	0890	XTO
0641	YTO	0691	5	0741	5	0791	DN	0841	X=Y	0891	0
0642	a	0692	1	0742	EEX	0792	X	0842	0	0892	GTO
0643	XFR	0693	XFR	0743	5	0793	DN	0843	8	0893	1
0644	IND	0694	4	0744	CHS	0794	J	0844	5	0894	0
0645	a	0695	1	0745	XEY	0795	UP	0845	1	0895	0
0646	XEY	0696	UP	0746	-	0796	.	0846	GTO	0896	6
0647	XFR	0697	UP	0747	YTO	0797	0	0847	1	0897	0
0648	3	0698	3	0748	4	0798	0	0848	0	0898	9
0649	6	0699	5	0749	3	0799	2	0849	4	0899	0

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0900	0	0950	0	1000	0	1050	PNT	1100	5	1150	N
0901	X<Y	0951	0	1001	0	1051	CNT	1101	RUP	1151	X
0902	0	0952	0	1002	6	1052	CNT	1102	CHS	1152	XEY
0903	9	0953	X<Y	1003	8	1053	CNT	1103	UP	1153	XTO
0904	1	0954	0	1004	XTO	1054	CNT	1104	UP	1154	5
0905	4	0955	9	1005	0	1055	CNT	1105	RUP	1155	0
0906	2	0956	6	1006	XFR	1056	CNT	1106	PNT	1156	XTO
0907	XTO	0957	6	1007	0	1057	CNT	1107	UP	1157	+
0908	0	0958	5	1008	UP	1058	CNT	1108	XFR	1158	6
0909	GTO	0959	XTO	1009	3	1059	CNT	1109	2	1159	7
0910	1	0960	0	1010	X	1060	CNT	1110	UP	1160	PNT
0911	0	0961	GTO	1011	6	1061	CNT	1111	9	1161	UP
0912	0	0962	1	1012	8	1062	CNT	1112	0	1162	XFR
0913	6	0963	0	1013	+	1063	CNT	1113	X=Y	1163	7
0914	4	0964	0	1014	YTO	1064	CNT	1114	1	1164	+
0915	5	0965	6	1015	a	1065	CNT	1115	1	1165	XFR
0916	0	0966	5	1016	XFR	1066	CNT	1116	2	1166	1
0917	0	0967	0	1017	IND	1067	CNT	1117	3	1167	RUP
0918	X<Y	0968	0	1018	a	1068	CNT	1118	GTO	1168	X
0919	0	0969	0	1019	K	1069	CNT	1119	1	1169	XFR
0920	9	0970	0	1020	4	1070	UP	1120	1	1170	4
0921	3	0971	X<Y	1021	UP	1071	XFR	1121	3	1171	9
0922	1	0972	0	1022	2	1072	5	1122	5	1172	+
0923	3	0973	9	1023	RUP	1073	1	1123	DN	1173	YTO
0924	XTO	0974	8	1024	+	1074	XSQ	1124	XEY	1174	3
0925	0	0975	4	1025	YTO	1075	UP	1125	UP	1175	5
0926	GTO	0976	6	1026	a	1076	XFR	1126	0	1176	DN
0927	1	0977	XTO	1027	XFR	1077	4	1127	X=Y	1177	XFR
0928	0	0978	0	1028	4	1078	2	1128	1	1178	2
0929	0	0979	GTO	1029	8	1079	X	1129	2	1179	M
0930	6	0980	1	1030	K	1080	2	1130	0	1180	UP
0931	9	0981	0	1031	4	1081	DIV	1131	9	1181	XFR
0932	0	0982	0	1032	RUP	1082	DN	1132	DN	1182	1
0933	0	0983	6	1033	-	1083	PNT	1133	XEY	1183	X
0934	0	0984	2	1034	XFR	1084	XTO	1134	UP	1184	DN
0935	X<Y	0985	5	1035	IND	1085	4	1135	DN	1185	XEY
0936	0	0986	0	1036	a	1086	7	1136	M	1186	-
0937	9	0987	0	1037	X	1087	X	1137	XEY	1187	XFR
0938	4	0988	0	1038	1	1088	XFR	1138	X	1188	3
0939	8	0989	0	1039	RUP	1089	8	1139	YTO	1189	5
0940	4	0990	X<Y	1040	XEY	1090	X	1140	4	1190	DIV
0941	XTO	0991	1	1041	-	1091	XFR	1141	9	1191	XEY
0942	0	0992	0	1042	YTO	1092	5	1142	YTO	1192	L
0943	GTO	0993	0	1043	a	1093	1	1143	+	1193	0
0944	1	0994	3	1044	XFR	1094	UP	1144	6	1194	PNT
0945	0	0995	7	1045	IND	1095	0	1145	5	1195	XTO
0946	0	0996	XTO	1046	a	1096	X<Y	1146	XEY	1196	2
0947	6	0997	0	1047	RUP	1097	1	1147	PNT	1197	N
0948	4	0998	GTO	1048	+	1098	1	1148	XFR	1198	DIV
0949	0	0999	1	1049	DN	1099	0	1149	2	1199	DN

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1200	--XTO	1250	-- 7	1300	-- I	1350	--PNT	1400	-- J		
1201	-- 1	1251	-- 5	1301	--XSQ	1351	--XFR	1401	-- .		
1202	--PNT	1252	--FMT	1302	-- 0	1352	-- 6	1402	-- B		
1203	--PNT	1253	--FMT	1303	-- N	1353	-- 3	1403	-- .		
1204	--GTO	1254	--XTO	1304	--XTO	1354	--PNT	1404	--IND		
1205	-- 1	1255	-- E	1305	-- A	1355	--XFR	1405	-- .		
1206	-- 2	1256	-- N	1306	-- L	1356	-- 6	1406	--CNT		
1207	-- 4	1257	--YTO	1307	--FMT	1357	-- 1	1407	--CNT		
1208	-- 0	1258	-- I	1308	--GTO	1358	--PNT	1408	-- 7		
1209	-- 9	1259	-- 0	1309	-- 1	1359	--XFR	1409	-- 6		
1210	-- 0	1260	-- N	1310	-- 3	1360	-- 6	1410	-- .		
1211	--PNT	1261	-- .	1311	-- 4	1361	-- 4	1411	-- 0		
1212	--XTO	1262	-- .	1312	-- 0	1362	--PNT	1412	-- 0		
1213	-- 2	1263	-- .	1313	--FMT	1363	--XFR	1413	-- 6		
1214	--XFR	1264	-- .	1314	--FMT	1364	-- 6	1414	--CLR		
1215	-- 1	1265	--XSQ	1315	-- C	1365	-- 6	1415	--CLR		
1216	-- UP	1266	-- E	1316	-- A	1366	--PNT	1416	--CLR		
1217	--XFR	1267	-- α	1317	-- B	1367	--PNT	1417	--CLR		
1218	-- 7	1268	-- 0	1318	-- L	1368	-- UP	1418	--CLR		
1219	-- -	1269	--FMT	1319	-- E	1369	--XFR	1419	--FMT		
1220	-- DN	1270	--GTO	1320	--CNT	1370	-- 6	1420	-- K		
1221	--XTO	1271	-- 1	1321	-- A	1371	-- 7	1421	--CLX		
1222	-- 1	1272	-- 3	1322	-- π	1372	--PNT	1422	--GTO		
1223	--PNT	1273	-- 4	1323	-- π	1373	-- +	1423	-- 0		
1224	--PNT	1274	-- 0	1324	-- α	1374	-- DN	1424	-- 0		
1225	--CNT	1275	--XFR	1325	-- 0	1375	--PNT	1425	-- 0		
1226	--CNT	1276	-- 2	1326	-- YE	1376	--XFR	1426	-- 0		
1227	--CNT	1277	-- UP	1327	-- .	1377	-- 6	1427	--END		
1228	--CNT	1278	-- 0	1328	--CLR	1378	-- 5				
1229	--CNT	1279	--X>Y	1329	-- 0	1379	--PNT				
1230	--CNT	1280	-- 1	1330	-- N	1380	--PNT				
1231	--CNT	1281	-- 2	1331	--CNT	1381	--FMT				
1232	--CNT	1282	-- 8	1332	--YTO	1382	--FMT				
1233	--CNT	1283	-- 9	1333	--1/X	1383	-- α				
1234	--CNT	1284	--GTO	1334	-- α	1384	-- E				
1235	--CNT	1285	-- 0	1335	-- F	1385	-- A				
1236	--CNT	1286	-- 4	1336	-- A	1386	-- D				
1237	--CNT	1287	-- 5	1337	-- C	1387	--XFR				
1238	--CNT	1288	-- 6	1338	-- E	1388	--CNT				
1239	--CNT	1289	--FMT	1339	--FMT	1389	-- N				
1240	-- UP	1290	--FMT	1340	--XFR	1390	-- E				
1241	-- 0	1291	-- C	1341	-- 4	1391	-- YE				
1242	--X>Y	1292	-- A	1342	-- 1	1392	--XTO				
1243	-- 1	1293	-- B	1343	--PNT	1393	--CNT				
1244	-- 2	1294	-- L	1344	--XFR	1394	-- π				
1245	-- 5	1295	-- E	1345	-- 2	1395	-- α				
1246	-- 2	1296	--CNT	1346	--PNT	1396	-- 0				
1247	--GTO	1297	-- N	1347	--XFR	1397	-- B				
1248	-- 1	1298	-- 0	1348	-- 1	1398	-- .				
1249	-- 2	1299	-- α	1349	--PNT	1399	--CLR				

STORAGE REGISTERS

STORAGE	
b	n_W (=1 AT START)
a	Ind. Use
000	n_{GD}
001	F_T
002	θ
003	Z_B
004	Z_S
005	K
006	10 to 10
007	$W_T/_{000} \rightarrow Wt_K$
008	Area front
009	Diam. ft
010	
011	$Z_1 = Z_B$
012	W_1, fps
013	Z_2
014	W_2
015	Z_3
016	W_3
017	Z_4
018	W_4
019	Z_5
020	W_5
021	Z_6
022	W_6
023	Z_7
024	W_7
025	Z_8
026	W_8
027	Z_9
028	W_9
029	Z_{10}
030	W_{10}
031	Z_{11}
032	W_{11}
033	Z tict
034	
035	Temp.
036	Temp
037	1.6878
038	a_0 } %
039	a_1 } %

040	
041	Z
042	ρ, slug/ft^3
043	μ
044	
045	
046	$W_{tas} = V_T$
047	q
048	R
049	D_H
050	D_W
051	$\sqrt{N}$
052	
053	
054	
055	
056	
057	
058	
059	
060	h
061	ΣH
062	j
063	ΣJ
064	ΣK
065	ΣD_H
066	ΣWt_K
067	ΣD_W
068	
069	
070	π or C_D
071	R_B } 1
072	C_{DB} } 1
073	K_R } 1
074	R_B } 2
075	C_{DB} } 2
076	K_R } 2
077	R_B } 3
078	C_{DB} } 3
079	K_R } 3

080	R_B } 4
081	C_{DB} } 4
082	K_R } 4
083	R_B } 5
084	C_{DB} } 5
085	K_R } 5
086	R_B } 6
087	C_{DB} } 6
088	K_R } 6
089	R_B } 7
090	C_{DB} } 7
091	K_R } 7
092	R_B } 8
093	C_{DB} } 8
094	K_R } 8
095	
096	
097	
098	
099	
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103	
104	
105	
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107	
108	

3.6.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution. For a discussion of the particulars of this problem, see Section 4.

```
PROGRAM #76.006
2- DIMENSIONAL
TETHER CABLE
      14000.000   -Balloon Alt.,ft.MSL
       4000.000   -Surface Alt.,ft.MSL
          3.142   -π for Internal Cd
          0.280   -Diam.of Cable,in.
         25.000   -Cable WT. per 1000 ft.,lbs
        500.000   -Lengtl. K. Element,ft.
       1378.000   -Total Balloon Force,lbs
         79.400   -Angle of Force,deg.

ENT.WIND FIELD
          1.000   -First Wind Point
      14000.000   -Alt.(Balloon),ft.MSL
         25.000   -Wind,knots

          2.000
      13000.000
         25.000

          3.000
      10000.000
         60.000

          4.000
       8000.000
        -15.000

          5.000
       5000.000
        -30.000

          6.000   -Last Wind Point
       4000.000   -Alt.(Surface),ft.MSL
        -20.000   -Wind, knots

      13508.532   -Alt.,Bottom-of Element
        491.468   -Vert.Dist-top to bottom
        491.468   -Tot.Vert Dist.to Balloon
         91.976   -Horiz.Dist-top to bottom
         91.976   -Tot.Horiz.Dist.to Balloon
        500.000   -Cable Length
         12.500   -Cable Weight
         25.000   -Wind at element bottom
       4405.541   -Reynolds Number
          0.980   -Drag Coefficient
          1.354   -Dynamic Presssure
         15.480   -Element Drag
         15.216   -Horiz.Drag Component
          2.848   -Vert. Drag Component
         78.654   -Angle of Next Element Down
       1365.829   -Tension,Top of Next Element

      13018.304
        490.329
        981.696
         98.366
        190.341
       1000.000
         25.000
         25.000
       4452.354
          0.980
          1.369
         15.652
         15.346
          3.079
         77.888
       1353.694

      12529.435
        488.869
       1470.565
        104.916
        295.257
       1500.000
         37.500
         30.490
       5485.769
          1.043
          2.058
         25.035
         24.477
          5.253
         76.706
       1341.758

      12042.832
        486.602
       1957.168
        114.970
        410.227
       2000.000
         50.000
         36.167
       6560.757
          1.100
          2.914
         37.386
         36.385
          8.597
         74.972
       1330.202
```

```
 4171.457          4044.411
   42.327            42.358
 9828.543          9955.589
   26.616            26.566
 5065.615          5145.361
11200.000         11350.000
  280.000           283.750
  -21.715           -20.444
 4173.685          3944.320
    0.980             0.980
    1.015             0.904
   -1.160            -1.034
   -0.982            -0.876
   -0.618            -0.549
   57.862            57.924
 1146.479          1143.303

 4129.118          4002.044
   42.338            42.367
 9870.882          9997.956
   26.598            26.553
 5092.213          5171.913
11250.000         11400.000
  281.250           285.000
  -21.291           -20.020
 4097.544          3867.254
    0.980             0.980
    0.977             0.868
   -1.117            -0.993
   -0.946            -0.841
   -0.594            -0.527
   57.884            57.940
 1145.420          1142.244

 4086.769
   42.349
 9913.231
   26.581
 5118.795
11300.000
  282.500
  -20.868
 4021.086
    0.980
    0.940
   -1.075
   -0.911
   -0.572
   57.905
 1144.362
```

CABLE APPROX.
ON SURFACE

```
        4002.044   -Altitude (~Surface)
          57.940   -C. Angle at Winch
        1142.244   -C. Tension at Winch

        9997.956   -Vert.Dist.,Baln.-Winch
        5171.913   -Horiz.Dist.,Baln.-Winch
       11400.000   -Tot.Cable Length
         285.000   -Tot.Cable Weight

         101.441   -Tot.Vert.Drag Comp.
         386.441   -Sum-C.Wt.+Vert.Drag
         352.825   -Tot.Horiz.Drag Comp.
```

READY NEXT PROB.

J.B.W. 76.006

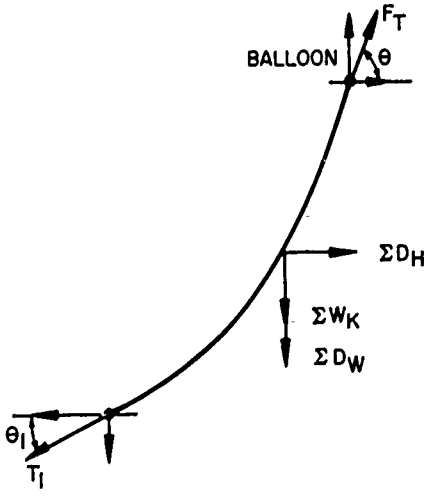
3.6.8 NOTES

A. If incorrect data is inputted, do not press STOP END to restart program. For correct restart to clear all registers press following:

STOP
GO TO
1
3
8
1
CONT

B. Ditto No. 1 above if computations underway and decide that something is in error or bad problem.

C. Proof of correctness of solution can be made by summation of the vert. and horizontal forces. θ_1 and T_1 are conditions at the winch in last group of program output as are ΣDH, ΣW_K, ΣD_W.



Horizontal: $T_1 \cos \theta_1 = \Sigma D_H + F_T \cos \theta$

Vertical: $T_1 \sin \theta_1 + \Sigma W_K + \Sigma D_W = F_T \sin \theta$

4. EXAMPLE OF A CONVENTIONAL TETHERED BALLOON PROBLEM

A. Given:

1. A requirement to fly a 100-lb payload at 18,000 ft MSL (but will accept 13,000 ft MSL if necessary) in New Mexico location where the surface is 4000 ft MSL. The most severe wind profile for the season and time of day needed for the particular type of experiment is as follows:

Altitude, ft	Wind, knots
18,000	25
13,000	25
10,000	60
8000	-15
5000	-30
4000	-20

2. Two balloons are in the inventory which might be capable of acting as the carrier.

	A. Lee Bridge Kite Balloon	B. Family-2 Balloon
Balloon Volume, V_B:	30,000 CF	45,000 CF
Ballonet Volume, v:	8000 CF	13,522 CF
Balloon Weight, W_B:	725 lb	970 lb
Instrumentation weight, W_I:	100 lb (at Conf. Pt.)	150 lb (at Conf. Pt.)
Payload Weight, W_P:	100 lb (at Conf. Pt.)	150 lb (at Conf. Pt.)

3. A single tether cable is desired.

Question: What is the smallest balloon capable of doing the job?

Approach: Run Program 76.001 to

(a) Select smallest balloon

(b) Check max. altitude capability of ballonet

Answer: See 3.1.7: 30,000 CF balloon capable of 13,906 ft MSL
45,000 CF balloon capable of 15,324 ft MSL
However, the 45,000 CF produces 347 lb lift (tension) at the ground when the balloon is at 15,324 ft MSL while the smaller balloon produces an unacceptably small 120 lb at its max altitude. Therefore, select the Family-2 45,000 CF unit. Make the max altitude 14,000 ft MSL for this project. Minimum lift at the ground (cable tension) is 464 lb under this no-wind condition. A Kevlar cable having the following properties was selected in the above computations.

Diameter: 0.28 in.
Wt/1000 ft: 25 lb

Question: Is this preliminary selection of balloon and cable satisfactory for the loads imposed by the maximum wind field?

Approach: Run Program 76.004 for most precise balloon total force and and angle at 14,000 ft (optional).
Run Program 76.005 for balloon total force and angle at 14,000 ft and at 1000-ft increments downward to and including surface.
Run Program 76.006 with 14,000 ft altitude output values from 76.005 and at other altitudes as judged necessary to obtain cable parameters - tension, position, etc.

Answers: See Sections 3.4.7, 3.5.7, and 3.6.7.

At 14,000 ft:	76.004	76.005
Total Force:	1385 lb	1378 lb
Angle to Horizon:	79.4°	79.4°
Trim Angle of Attack:	7.57°	7.49°

The slight disagreement is due to differences in the precision of locating the center of pressure and the impracticality of obtaining an exact trim amount of 0.0 The output of 76.005 is of acceptable precision. Its output at decreasing altitudes can be scanned, noting that when the balloon is at 10,000 ft the total force reaches a maximum level of 3500 lb at an angle of 66.9°. While the trim angle is a low 4.5° due to the 60 knot wind,* the aerodynamic lift is 3262 lb producing a total lift of 4445 lb. This loading equals the working strength of the cable thereby suggesting that the balloon should be raised or lowered with caution during these wind conditions. Note that the ballonet is 0.9 full when the balloon is at the surface.

The output values of 76.005 at 14,000 ft were then used as inputs to 76.006 to determine cable conditions and location from 14,000 ft, down to the surface. The final group of figures in the 76.006 output indicate the following

Cable Angle:	57.9° above horizon
Winch Tension:	1142 lb
Horiz. Displacement:	5172 ft (Balloon-Winch)
Cable Length:	11,400 ft
Cable Wt.	285 lb

Intermediate groups of figures below the 14,000 ft altitude can be used to plot various cable parameters including its space position along its entire length from the balloon to the ground.

*This decrease of trim angle with wind speed to decrease aerodynamic lift can be shown by running a series of increasing wind values in 76.004 or 76.005.

The overall conclusion would be that the 45,000 CF balloon with a 7000 break strength cable weighing 25 lb per 1000 ft is an acceptable system for the conditions specified. To determine whether it can be raised to or lowered from its maximum altitude output values for altitudes below 14,000 ft from Program 76.005 should be run in Program 76.006

5. PRELIMINARY PARAMETRIC STUDIES OF THE HIGH ALTITUDE TETHERED BALLOON PROBLEM

The concept for a tethered-balloon flight to 20 km MSL first evolved from a study of minimum wind expectancy over possible tethered balloon sites. Tropical latitudes appeared to be ideal since they have the greatest number of months per year where the magnitude of the winds from the surface to 20 km could be considered acceptable for raising or lowering the balloon. Too large a wind velocity (dynamic pressure) causes excessive drag on the balloon and cable tending to cause blowdown of the system. Because of the desire to operate the first feasibility tests at the AFGL balloon test site at Holloman AFB, New Mexico, the study concentrated on the winds in this area. The July-August period has an acceptable minimum wind profile. The solid line in Figure 1 is a composite July-August 75 percent wind profile for Holloman AFB (White Sands Missile Range) and was selected as the standard for flight equipment and system design.

Based on a flight altitude of 65,616 ft MSL (20 km), a surface altitude of 4400 ft MSL, a payload of 200 lb and a cable weight of approximately 1700 lb, several natural shape balloons of varying sizes were considered as the first steps in system design. The balloon contractor then recommended a 500,000-CF and a 800,000-CF balloon.

The 500,000-CF balloon at altitude was found, by use of Program 76.006 to be too small. The program indicated that in the design wind field, the cable would become horizontal at approximately 17,000 ft MSL.

The larger 800,000-CF balloon was found to have acceptable lifting characteristics. Using the contractor's estimate of total force, F_T = 3073 lb and angle of the force θ = 81.6°, a series of Program 76.006 runs were made with variations of key parameters. Results are shown in Table 3.

The three lines shown in Group 1, Table 3, illustrate the effect of cable drag coefficient variations. It can be noted that the built-in variable cylinder drag coefficient yields the same results in this particular problem as the constant drag coefficient value of 1.0 at all altitudes and wind conditions. Thereafter all computations use the internal C_D techniques.

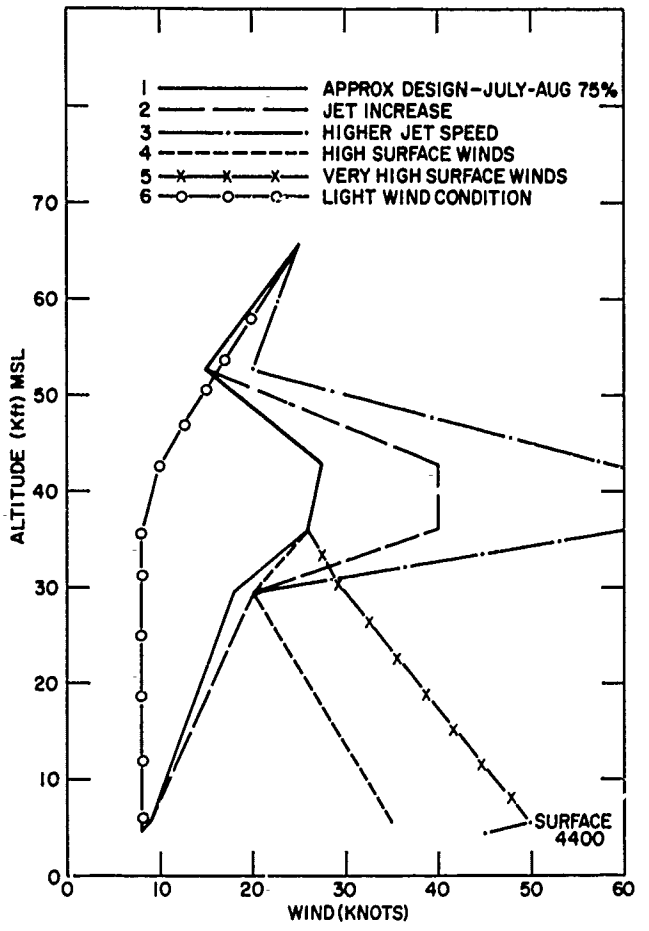


Figure 1. Wind Profiles - High Altitude Tethered Balloon

The effect of cable diameter and weights in Groups I, II, and III were investigated over a small range covering the possible characteristics of a finalized cable design. Note that the length of the cable required varies between approximately 65,000 and 68,000 ft for the 61,216-ft balloon height above the surface. The cable tension and angle at the winch remain at acceptable levels although the heaviest weight of cable investigated reduces the angle below 40°. The horizontal distance between the balloon and winch varies between 19,000 and 26,000 ft. This indicates a balloon elevation ("look") angle of between 67° and 73° from the winch.

Table 3. High-Altitude Tether-Cable

(BALLOON–800,000 CF. Natural Shape, Located at 65616 Ft. MSL, 61216 Ft. Above Surface)

	INPUT						OUTPUT						
	BALLOON		CABLE				CABLE						
Group	Wind Refr. Fig. 1	F_T lb	θ deg	C_D	Diam. in.	Wt. per 1000 ft lb	Length ft	Weight lb	Hor. Drag lb	Vert. Drag lb	Tension (At Winch) lb	Angle (At Winch) deg	Horizontal Displacement Ball. – Winch ft
I	No. 1	3073	81.6	1.0	.3	25	65300	1632	456.4	152.9	1547	54.2	20760
	"	"	"	1.2	"	"	66199	1652	536.6	192.9	1548	50.5	22548
	"	"	"	IN *	"	"	65300	1632	453.0	150.9	1547	54.3	20761
II	No. 1	3073	81.6	IN *	.3	27.5	65900	1812	446.2	156.1	1396	50.1	22133
	"	"	"	"	"	30	66900	2007	438.1	161.4	1243	44.5	23961
	"	"	"	"	"	32	68000	2176	430.1	165.4	1123	38.5	25838
III	No. 1	3073	81.6	IN *	.25	25	64700	1618	386.4	120.9	1546	57.3	19398
	"	"	"	"	"	27.5	65200	1793	381.3	125.2	1396	53.5	20618
	"	"	"	"	"	30	66000	1980	375.4	129.9	1243	48.4	22199
	"	"	"	"	"	32	67000	2144	368.8	134.5	1121	42.7	24052
IV	No. 6	3073	81.6	IN *	.3	25	63000	1575	136.7	35.2	1545	67.7	14564
	No. 2	"	"	"	"	"	68200	1705	661.8	251.4	1551	44.3	26724
	No. 3	"	"	"	"	"	82800	2070	1043.9	502.8	1564	17.4	47555
	No. 4	"	"	"	"	"	69100	1728	924.4	580.6	1560	28.0	26687
	No. 5	"	"	"	"	"	86000*	2150*	1157.1*	910.0*	*Did not reach grnd.	= 0 at 5692 ft MSL	46713*
V	No. 1	3325	79.5	IN *	.3	25	65800	1645	444.6	162.8	1800	54.2	22676
	"	2979	81.5	"	"	"	65600	1640	448.6	154.6	1454	52.3	21592

* IN – Internal Cylinder Drag Coefficient

Data in Group IV show the effects of variations in wind profiles below the balloon per Figure 1. In general, higher winds have adverse effects; increases in cable length and horizontal displacement and a decrease in cable angle at the winch. Increases in winds at lower altitudes are more pronounced in their effect due to the higher atmospheric density effect on cable drag. In one case the cable is not able to reach the ground due to the excessive cable drag for a 45 to 50 knot surface wind.

It can be also shown that a given cable density produces a constant cable tension at the winch regardless of cable length and/or wind magnitude. The chief effect of increased total cable weight is to decrease the angle of the cable at the winch. Reference to Section 3.6.8, indicates the balance of forces to show the interaction of horizontal and vertical drag with the balloon forces and winch tension.

Group V are two other possible sets of values for balloon total force and angle which appear to cover the range of uncertainty in these parameters. Further work is needed in establishing the full-scale (large Reynolds numbers) aerodynamic characteristics of natural-shaped balloons so that their characteristics can be used as inputs into Program 76.003. In this case of the high-altitude tethered balloon, the problem is made further complex by the technique required to raise the balloon from the ground. Unlike the usual tethered balloon, the design selected does not contain a ballonet. Such a design requires the balloon to be reefed during its ascent to prevent loose uninflated sections from acting as a sail.

On the ground the top of the balloon is nearly filled with an amount of gas sufficient to expand to the full 800,000 CF volume of the balloon at 65,600 ft MSL. The excess material below this initial small bubble is gathered, during fabrication, into a small diameter bundle and secured by a number of bands along its length that are called reefing points. The reefing points are secured by squib/cutters that can be fired by radio command or by pressure sensors. As the balloon ascends, the initial bubble expands until a predetermined level of "tightness" or bottom cone angle is reached. The top reefing point is then released allowing part of the excess material to be free for additional gas expansion during further ascent. This procedure continues, one reefing point at a time, until the balloon material is completely free some distance below the maximum altitude.

Thus the aerodynamic shape and volume of the balloon is constantly changing in a combination of gradual as well as stepped phenomena. Because of the difficulty in assigning aerodynamic coefficients to such a varying body, at this time no attempt has been made to run the system at lower than the maximum altitude. The first attempt will probably involve assumptions of a smaller natural shape balloon with a small diameter cylinder attached and the system scaled for the altitude of maximum dynamic pressure in the design wind profile, (approximately 40,000 ft MSL).

Appendix A

Density Ratio

The ratio of atmospheric density at altitude to that at sea level is a parameter common to many kinds of balloon calculations. The usual method in calculations is to refer to some type of table which gives the ratio at discrete altitude levels. The usual reference atmosphere is the U.S. Standard Atmosphere, 1962, but the 1966 Supplements may be used if more applicable for specific locations or seasons.

The use of a table-lookup technique in conjunction with computer problem solving would be nearly unworkable. A simple relationship between altitude and density ratio is therefore needed. The altitude density ratio variation is nearly logrithimic.

Use of an equation in the quadratic form was found to give a correlation of 0.999.

$$\ell_n \rho/\rho_o = a_o + a_1 Z + a_2 Z^2 \qquad \text{(A1)}$$

Using a curve fit program, the constants were found to be:

Z = 0 to 75,000 ft	Z = 0 to 25,000 ft
ΔZ = 5,000 ft	ΔZ = 1000
$a_o = +5.06595^{-3}$	$a_o = -3.94580^{-4}$
$a_1 = -2.83164^{-5}$	$a_1 = -2.90568^{-5}$
$a_2 = -1.76842^{-10}$	$a_2 = -1.19042^{-10}$
$r^2 = .99964$	$r^2 = .999999$

It might be noted that when the altitude is zero, the density ratio is not unity.

By use of a different form:

$$\ell_n \rho/\rho_o = a_o Z + a_1 Z^2 \qquad \text{(A2)}$$

or

$$\frac{\ell_n \rho/\rho_o}{Z} = a_o + a_1 Z$$

and the use of a curve fit from Z = 0 to 75,000 ft, the constants were found to be

$a_o = -2.81361^{-5}$

$a_1 = -1.7772^{10}$

$r^2 = .984$

The density ratio is 1.0 at sea-level. The lower degree of correlation was considered to be acceptable for the type of solutions used in the balloon programs. Therefore Eq. (A2) is used in all of the programs to obtain atmospheric density as defined by the U.S. Standard Atmosphere, 1962. However, Eq. (A1) can be sub-substituted when a greater degree of correlation is required.

Appendix B

Symbols and Definitions

A - Cable Frontal Area, 76.006

A_o - in X_{CB} Equation, 76.005

a_o - Constant in Density Ratio Equation (also for X_{CB}, 76.004)

a_1 - Constant in Density Ratio Equation (also for X_{CB}, 76.004)

a_2 - Constant in X_{CB} Equation, 76.004

a - Lift Curve Slope

b - Minimum Drag Coefficient C_{DO}

c - $dC_D/d\alpha^2$

$\overline{c}$ - Length of Balloon Envelope

d - Cable Diameter

f_o f_1, f_2
- Constants in X_{CB} Equation 76.005

g_o, g_1, g_2, g_3
- Constants in X_{CB} Equation, 76.005

H - Height, Surface to Point Indicated

H_p - Height of Tritether Apex

h - Horizontal Projected Length of One Cable Element

j - Vertical Projected Length of One Cable Element

K - Length of One Cable Element, 76.006

K - $q\ V_B^{2/3}$

ℓ - Length of Cable

ℓ_{ext} - Length of Extension Cable

m - Length, $X_{CG} - X^{CP}$

n - Length, $Y_{CG} - Y^{CP}$

r - Length $X - X^{CP}$ ($X = X_{CP}$ in 76.004 and 5; X_{ARC} in 76.003)

s - Length, X - X^{CP} (Y = Y_{CP} in 76.004 and 5; = X_{ARC} in 76.003)

t - Length, X_{CB} - X^{CP}

u - Length, Y_{CB} - Y^{CB}

X-AXIS - Centerline of Aero. Shaped Balloon, X = 0 at Nose

Y-AXIS - Normal to X-AXIS at X = 0, Y = 0 at Nose, Y Positive above Centerline

X^{CP} - X Station of Confluence Point

Y^{CP} - Y Station of Confluence Point

X_{CP} - X Station of Center of Pressure

Y_{CP} - Y Station of Center of Pressure

X_{CB} - X Station of Center of Buoyancy

Y_{CB} - Y Station of Center of Buoyancy

X_{ARC} - X Station of Aerodynamic Reference Center

Y_{ARC} - Y Station of Aerodynamic Reference Center

x - Distance Between Twin-Tether Ground Anchor Points

L_G - Gross Lift; Gas Volume x Specific Lift of Helium

L_n - Y Component of Gross Lift

L_a - X Component of Gross Lift

L_A - Aerodynamic Lift

D - Aerodynamic Drag

T - Total Aerodynamic Force

N - Y Component of Total Aero Force

A - X Component of Total Aero Force

M_o - Aero Pitching Moment about Aero Refr. Center, 76.003

C_M - Pitching Moment Coefficient, $M_o/q\ V_B^{2/3}\ \bar{c}$, 76.003

C_L - Lift Coefficient, $L_A/q\ V_B^{2/3}$

C_D - Drag Coefficient, $D/a\ V_B^{2/3}$

W_B - Weight of Balloon

W_I - Weight of Instruments

W_P - Weight of Payload

W_e - Weight of Extra Items

W_c - Weight of Cable

L - Total Lift, $L_G + L_A$

L_N - Net Lift, $L - (W_B + W_I + W_P + W_e)$

q - Dynamic Pressure, $1/2\rho\ V^2 = 1/2\rho\ \text{Wind}^2$

V_B - Volume of Balloon

v - Volume of Ballonet

F_T - Total Balloon Force at Confluence Point

W - Wind (Also V)

W - Wind Velocity Normal to Cable

V_n - Wind Velocity Normal to Cable

R - Reynolds Number

T - Cable Tension

Z - Altitude, ft, MSL

Greek Symbols

α - Balloon Angle of Attack

α - Multi-tether Cable Angle at Ground, 76.001

β - Multi-tether Plane Angle at Ground, 76.001

γ - Ballonet Fullness Factor

Δ - Increment

Σ - Sum

θ - Angle of F_T or Cable Above Horizon

ρ - Atmospheric Density

μ - Coefficient of Viscosity of Air

π - To Call Special Operation

Subscripts

o - Sea Level

B or b - Balloon

d - Design

S or s - Surface

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